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METHODS AND INSTRUMENTS USED IN MINERALOGY*

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Examination of the materials at and near the surface of the earth proves that, if we disregard plants and animals, they consist of various kinds of masses, such as rocks, soils, and ores of different types, disposed according to definite patterns expressive of their modes of formation and subsequent history. Closer study reveals that these rocks and ores consist in turn of one or more substances of different properties and aspects. These smaller units are called minerals. Each mineral is more or less homogeneous in chemical composition and is commonly recognized wherever it occurs by certain distinguishing characteristics or features.

Mineralogy is the branch of science which describes and classifies minerals, ascertains the physical and chemical properties of each mineral and determines its crystal form and crystal structure, if it is crystallized.

Interest in minerals and crystals extends back to primitive peoples who were attracted to them by the variety of forms and colors which they present and by their appeal when properly cut and mounted in jewelry. The perfection of workmanship and the art and skill attained by these peoples in the shaping and mounting of various minerals and gems is extraordinary. Their tools and methods were of the crudest type; but perseverance and the urge to make ornaments for themselves and for votive offerings to their gods accomplished results that delight the archaeologist and give pleasure to us of the present day. Intrinsically beautiful, they serve as important historical documents indicative of the state of culture of the races that fashioned them.

It is the object of this talk to consider briefly a few of the methods and instruments now in use by mineralogists in determining the physical, crystallographical, and chemical properties of minerals. Experience has proved that in experimental work the introduction of a new method or a new instrument may enable the observer to explore new fields heretofore inaccessible because of lack of the proper weapons of attack. Under present war-time surroundings this condition is forcibly impressed upon us

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and we realize the importance of adequate supplies of the instruments of warfare and of new methods and weapons of defense and of offense.

In 1609 Galileo made a telescope by grinding and polishing a simple biconvex objective lens and a biconcave eyepiece lens and mounting them at the opposite ends of a tube. With this new optical instrument, of which he had had only a brief description from Holland, he was able to make ships at a distance appear much closer. The quality of the glass in his lens elements was poor and, at the magnification of 33 diameters obtained by his telescope, the quality of the image was extremely poor. However, on January 9, 1610, he pointed his telescope at the heavens, at the sun, the moon, Venus, and Jupiter, and began a series of exciting discoveries. He studied the movement of sun spots and proved that the sun is rotating; he studied the moon and found, that, contrary to the opinion of philosophers, its surface is not smooth but mountainous in certain areas; he measured roughly the heights of several lunar mountains by the lengths of the shadows they cast; he studied Venus and noted its phases not unlike those of the moon; he studied Jupiter and discovered its four large satellites, recorded their periods of revolution and concluded that he had before his eyes a miniature system similar to that postulated by Copernicus for the solar system. It has been said that Galileo's observations on the satellites of Jupiter served to convince people of the validity of the Copernican theory of the solar system in spite of the opposition to the theory by the Church, and in later years to Galileo himself. The introduction by Galileo of the telescope to the study of the heavenly bodies opened a new era in astronomy.

Forty years later the compound microscope was invented in Holland. By its use much of interest, especially in the biological field, was discovered; but the quality of images produced by it was too poor to permit adequate magnification. For 150 years its usefulness was restricted because of poor design of the objective lens and poor quality of available glass. The result was that this tool now so successfully employed in mineralogical work did not at once give to mineralogy the impetus that the telescope gave to astronomy. However, in 1669 Nicolas Steno did observe the shapes of crystals precipitated from solution on a slip of glass and asserted that, for a given chemical salt, the shapes of the crystal faces formed may vary from crystal to crystal but not the interfacial angles. This is the first statement of the constancy of crystal angles more definitely proved a century later by Romé de l'Isle in 1783 and by Haüy in 1784 with the aid of the contact goniometer invented by Carangeot, assistant to Romé de l'Isle.

Reflecting goniometer. The contact goniometer was followed in 1809 by the single-circle reflecting goniometer of Wollaston. With its introduction

precision measurement of crystal angles began and engaged the attention of crystallographers in Europe. In 1874 Miller constructed a two-circle goniometer by adding a vertical circle to the usual horizontal circle instrument; this arrangement was modified by Fedorov in 1889 who used an autocollimating telescope in place of the collimator and telescope. In 1893 three two-circle goniometers were described, one by Fedorov, the second by Czapski, and the third by Victor Goldschmidt. Of these the design by Goldschmidt has proved to be the best and is now widely used and has been of the greatest aid to crystallography. In 1889 and 1904 G. F. Herbert Smith described two models of a three-circle goniometer. Impressed by the usefulness of the measurement of crystal faces in a zone, he employed the third circle to aid in the setting of a crystal so that the angles in any one of its zones can be measured directly on the horizontal circle. The three-circle goniometer was also used for the solution of spherical triangles. Although the three-circle goniometer is interesting and serves its purpose well, it has not been adopted as a tool by mineralogists.

Crystal goniometers have served for purposes other than the measurement of angles. In 1889 V. Goldschmidt described a cutting goniometer for making models of actual crystals. In 1894 Tutton exhibited his single-circle crystal-grinding goniometer which he used later in preparation of the crystal plates and prisms for his extended investigations into the isomorphous series of the orthorhombic sulphates and selenates of potassium, rubidium, and cesium, and into other isomorphous series. In 1915 F. E. Wright described a two-circle crystal-grinding goniometer for grinding faces of any desired orientation on a crystal and accurate in position to one-half minute of arc. Orientated faces on crystals of quartz, calcite, and other minerals were ground with the aid of this apparatus and used in the measurement of the changes of crystal angles with changes of temperature. For the measurement of crystal angles at elevated temperatures a special electric resistance furnace, water-cooled on the outside and mounted on the horizontal plate of the Goldschmidt goniometer was constructed and measurements were made to temperatures of 1250°C . For measurements at low temperatures V. M. Goldschmidt constructed a special apparatus for surrounding the mounted crystal with an atmosphere approaching in temperature that of solid carbon dioxide, or of liquid air.

The equipment at present available for the measurement of crystal angles is satisfactory and adequate for crystals of appreciable size; but there is still room for improvement in the measurement of minute crystals and of small crystal faces only one-tenth millimeter in width. The amount of light reflected from such faces is so small that the reflection signals are

weak and spread out as a result of diffraction. At present the best procedure appears to be the use of an intense carbon arc lamp as a source of illumination together with a telescope having an objective lens of short focal length and nice adjustment of the entire optical system. The best results will be obtained with a goniometer of special design.

Instrument design. In this connection it is well to state that each instrument intended for precision work should be designed with reference both to purpose and rugged mechanical performance and to adjustment facilities, so that the observer will be in a position at any time to test the accuracy of adjustment of all parts of the instrument by an orderly procedure of successive adjustments so arranged that no later adjustment disturbs preceding adjustments. If this precaution is not taken, the observer is forced either to devise a makeshift method of adjustment, which is never satisfactory, or to place implicit faith in the skill of the manufacturer to furnish the instrument in correct adjustment and to rely upon maintenance of the adjustment in spite of the jars and jolts of transportation and the inevitable slight movements upon aging of the metals of which the instruments are made. Another result of long and sometimes bitter experience is the futility of the so-called universal instruments of a generation ago. Instruments of this type are likely to be unwieldy and of relatively poor design, so that they are not satisfactory for any one of the several kinds of measurement for which they are intended.

Projections. In the study of the crystallographical and optical properties of crystals certain projections are extremely useful. They enable the observer to gain oversight of the spatial relations under investigation and to obtain approximate values of the relative positions and distribution of the important points and directions in space. Experience has shown that different projections are needed for different purposes.

In crystallographic measurements the gnomonic projection (ascribed to Thales, 650 B.C.) is especially useful for plotting the polar and azimuthal angles of measurement; also for preparation of crystal drawings. In this projection crystal zones are represented by straight lines. The limitation of the projection is its large distortion and the fact that polar angles in excess of 70° are not convenient to plot.

The stereographic projection (Hipparchus, 150 B.C.), which is angle-true (conformal, orthomorphic) and in which all zones are great circles, is useful both for crystallographical and for optical work. It covers the hemisphere easily, but distorts polar angles increasingly as the margin of the hemisphere is approached. Another perspective projection, the orthographic (Hipparchus), in which the hemisphere to be projected is viewed from an infinite distance, is used but little in crystallographical and optical work. Interference figures, as observed in the petrographic micro-

scope, are orthographic projections of the interference phenomena observed in convergent polarized light and their measurements are made as in this projection.

Several other projections, the Lowry perspective and the globular or equidistant, in polar and meridional forms, distort less than the preceding projections and have this advantage in crystal optical studies. The equidistant projection is not a mathematical projection in the sense that each point of the sphere is projected according to a definite mathematical formula, but rather as a mode of representing the sphere on a plane by a series of easily constructed curves.

In recent years students in the field of petrofabric analysis, or study of the internal structure of a rock, have made extensive use of the Lambert equal-area meridional projection net, described by Lambert in 1772; this projection has been employed in cartographic work and atlases continuously since its introduction by Lambert. In 1925 Schmidt applied this projection net to problems in petrofabric analysis and in that field the projection is called the Schmidt projection net. It would seem that this practice of renaming a long established projection net, or in fact any other well known appliance or tool for accomplishing a given purpose, is not justified nor in keeping with scientific accuracy. A case similar to the 'Schmidt' net is the 'Wulff' stereographic net in use in crystal optics. Fortunately this designation is but little employed at present and the name stereographic projection net serves the purpose adequately. In the case of the Lambert equal-area projection net, however, the designation Lambert is needed to distinguish it from other equal-area projections in common use in cartographic work.

The petrographic microscope. For the measurement of the optical properties of minerals the petrographic microscope is the most important instrument available to mineralogists. Its development did not follow immediately upon the introduction of the reflecting goniometer. During the years 1814 to 1818 Sir David Brewster wrote a series of papers announcing his discovery of biaxial crystals and of the intimate relations between optical and crystallographical relations in crystals. In 1828 William Nicol, the inventor of the nicol prism, ground thin sections of rocks and mounted them in Canada balsam. In 1850 H. Clifton Sorby studied thin sections of rocks; between 1850 and 1861 he published the results of his investigations of certain rocks and demonstrated the possibilities of the petrographic microscope in the study of thin sections of rocks. He was followed in 1863 by F. E. Zirkel, who described a series of rocks. In 1870 and 1876, H. Rosenbusch constructed a practical petrographic microscope with rotating stage. During that decade interest in the petrographic microscope became general. Such microscopes were

manufactured in several countries and some of them are still in use. At the present time a number of petrographic microscopes of satisfactory design and quality are on the market.

The most important optical constants of a mineral for various wave lengths of light are: its principal refractive indices; its principal birefringences; the nature of the optical ellipsoid of reference (index ellipsoid); determination of the spatial relations between the principal planes of its index ellipsoid and its principal crystallographic directions (extinction angles for definite directions and zones).

Refractive indices are measured most easily by the immersion of fine mineral grains in refractive liquids or solids of known refractivity for a given wave length of light at a definite temperature. A number of liquids and mixtures of liquids are available to cover the range in refractive indices between 1.33 and 2.10; and in low melting solids to cover refractive indices up to 3.0 and even in excess of 3.0. For the comparison of the refractive index of a fine mineral grain with that of the surrounding liquid, either the Becke-line method or that of oblique illumination is used. The degree of accuracy attainable by these methods, under carefully controlled conditions, is about 2 in the fourth decimal place; at this limit the difference in intensity of illumination between the Becke-line, or oblique illumination effect, and the general field is just detectable by the eye; below it the gradational contrast is no longer perceptible to the eye. Determinations accurate to ± 0.001 in refractive index are easily made on favorable grains measuring only a few microns in diameter. For measurements in different parts of the spectrum, either the liquid mixture must be changed or the same liquid held at different temperatures. The decrease in refractive index of a liquid is commonly 0.001 per 2° to 3° C. rise in temperature. Determinations of the refractive indices of liquids are made either with the aid of a total reflecting refractometer or by the prism method on a spectrometer or goniometer. In either case only a drop of the liquid is required.

Birefringence measurements are made on crystal plates of uniform, known thickness by use of a birefracting graduated wedge or by tilting a plane-parallel plate to compensate the path difference produced by the mineral plate. In this measurement the thickness of the mineral plate is the chief element of uncertainty. Optic axial angles are determined by imaging the interference figure, formed in convergent polarized light, on a finely divided coordinate scale in the focal plane of a positive eyepiece; the scale may also be placed in the lower focal plane of the substage condenser and may then be graduated to read off angular distances directly. The angular equivalent of each scale division is ascertained either by computation or preferably by direct determination with the aid of an

Abbe apertometer or of the collimator of a goniometer. The optical character of a birefracting mineral is ascertained by use of a birefracting plate or wedge of known orientation.

Experience has shown that it is possible to determine these optical properties, and other less important optical characteristics, on mineral grains measuring only one one-hundredth millimeter in diameter.

Thin sections of rocks and of mineral aggregates are used primarily for the study of the morphological development of the various minerals and the relations between the mineral grains, rather than for the accurate measurement of their optical properties. With the Fedorov stage, however, determinations of optic axial angles and of positions of the planes of optical symmetry relative to crystallographic directions, especially in the feldspars, are made on thin sections of rocks. In recent years the Fedorov stage has been employed with great success in petrofabric analysis, to ascertain for a given mineral, such as quartz, the relative frequency of occurrence or distribution in space of a given crystallographic direction, such as the principal or optic axis. From this study of grain orientation in a rock mass, by use of sections cut along definitely known planes in a rock specimen whose orientation in the field has been ascertained, information is gathered on the present structure of the rock mass and on its deformation in the past. This combination of field and laboratory study is directly dependent on the information yielded by measurements with the Fedorov stage which in this field of scientific inquiry is indispensable.

Crystal structure. In 1784 Abbé René Just Haüy discovered the law of rational intercepts for crystals, stated the laws of crystal symmetry, showed that all varieties of crystal forms can be referred to a few types of symmetry, and that, for a given crystal substance, its cleavage and other crystal faces are related to a simple primitive form, characteristic of the crystal. He proposed an hypothesis for the orderly spatial arrangement of the 'molecules integrantes' within a crystal which finds expression in flat crystal faces and in the rationality of their intercepts on three crystallographical axes of reference. Although Haüy's explanation of crystal structure emphasized the idea that crystal units are stacked in parallel orientation, it was proved later to be defective for physical reasons; but it did arouse interest in crystals and their structure. This interest has continued to the present time.

Following Haüy, both crystallographers and mathematicians contributed to the purely geometrical aspects of the problem. By the end of the last century the problem had been solved through the labors chiefly of Hessel, Bravais, Gadolin, C. Jordan, Sohncke, Curie, Schoenflies, Fedorov, Barlow, and others. These studies were based on the assump-

tion that matter is not continuous but granular in nature and consists of atoms which in these studies may be considered to be indivisible and to be located at very small, but not indefinitely small, distances apart. In a solid these atoms may be clustered into chemical molecules, or groups of molecules (crystal particles), which in turn serve as its building units. In a crystal these units are in orderly arrangement, such that the field surrounding any single unit is exactly similar to that surrounding any other unit, with the exception of units situated near boundary surfaces. The crystal is thus homogeneous and each crystal particle, or fundamental cell, has the same orientation in space, while within each crystal particle the arrangement of the component atoms and molecules (groups of atoms) is exactly the same as in each other crystal particle. These assumptions lead to the conceptions of arrangements of the crystal particles along definite directions in space, to the grouping of these lines in definite planes, and to spatial groupings of parallel planes which constitute spatial crystal lattices. The study of the symmetry relations within these crystal lattices, the types of movements of translation and of rotation through finite distances to produce self coincidence led first to the establishment, by Bravais in 1848, of fourteen possible space lattices in which the crystal is considered to consist of molecules, alike and similarly oriented, whose centers of mass occupy the points of the space lattice. The Bravais fourteen space lattices encompass all holohedral crystals. Additional lattice types were developed by Sohncke through consideration of the positions of the atoms within the crystal particles and the resulting series of interpenetrating lattices. These considerations raised the number of possible crystal lattices to sixty-five. If the principle of enantiomorphous symmetry is introduced, the total number of geometrically possible structures on the assumption of three independent translations and no infinitesimal translation becomes two hundred and thirty; this number was reached independently by three investigators, Fedorov, Schoenflies, and Barlow, and by quite different methods of approach. It was furthermore proved that there are thirty-two, and only thirty-two, finite groups of movements that are consistent with the law of rational indices and hence valid in crystallography. These constitute the basis for the thirty-two classes of crystal symmetry groups.

In addition to the solution of the geometrical problems presented by space lattices possible in crystals, crystallographers had made great progress in the study of the behavior of isomorphous series of crystals and also of the effects produced on the crystallographical and physical properties of solutions in the crystal state by the step by step substitution of one metal base by another, and had learned much regarding the spatial relations within the crystal particle itself. They had also learned to think

in terms of face normals rather than in actual crystal faces and in crystal indices rather than in axial intercepts; also in polar forms and their graphical expression in the gnomonic projection. The time had arrived for the introduction of a new tool that would enable the investigator to probe into the actual crystal unit cells, to ascertain the relative positions of its component atoms, and to measure the exact distances between them.

This new tool was discovered by Roentgen in 1895 and named by him *x*-rays. He found that *x*-rays penetrate ordinary materials with ease. The next two decades were occupied by physicists in exploring the nature of *x*-rays and in putting them to practical uses, especially in the medical field.

In 1912 Laue, interested in *x*-rays and acquainted with the concepts of space lattices as developed by crystallographers, suggested that the space lattice of a crystal might serve as a space grating for *x*-rays and produce diffraction patterns on a photographic plate, if they were of the nature of light waves and of wave lengths smaller than the minute spacing intervals of a crystal space lattice; in other words, of lengths of the order of one ten-thousandth of the wave lengths of light waves. The experiment was tried by Friedrich and Knipping by sending an *x*-ray beam through a thin plate of copper vitriol. The result on the photographic plate was a diffraction pattern of adequate clarity to indicate the correctness of Laue's theoretical conclusion. The interest aroused by this experiment and others on crystals of the cubic system spread quickly; in the following year W. H. Bragg and his son, W. L. Bragg, introduced the spectrometer ionization-chamber reflection method which was widely adopted and served both in the analysis of the crystal structure of many crystal types and in the measurement of *x*-ray wave lengths themselves.

In 1916 Debye and Scherrer, and independently A. W. Hull, introduced the powder method which enabled observers to analyze crystal structures by the photographic method on crystal powders. The method was also adapted for use with the ionization chamber and spectrometer.

Still another method was developed in which a crystal of known orientation is rotated at constant speed about an axis normal to the impinging *x*-ray beam and coincident with the axis of a cylinder which is stationary and which carries a photographic film mounted against its inner surface. The resulting negative shows a series of diffraction spots spaced along parallel layer lines; by measurement both of the separation of the diffraction spots along the layer-lines and of the distances between the layer-lines, the cylindrical coordinates of each diffraction spot can be determined and, except for an element of uncertainty regarding identification of certain spots, the space lattice of the crystal can be determined.

This element of uncertainty was removed in 1924 by Weissenberg by use of the x -ray goniometer in which, during rotation of the crystal as in the simple rotation method, the photographic film is moved at a definite rate of translation and without rotation. A heavy metal cylinder with a narrow slot aperture cut normal to its axis is placed between the rotating crystal and the film in such position that only diffracted beams from a single layer-line are permitted to impinge on the film. At least four negatives are taken, one from the equatorial layer-line, one from the first layer-line, another from the second, and so on. This procedure is called the normal beam technique and is more rapid in application than the rigorous Bragg spectrometer ionization-chamber reflection technique. These two methods are, however, complementary; the Bragg method is particularly well adapted to the measurement of large crystals; the Weissenberg method to that of small crystals.

Recently an important advance has been made by M. J. Buerger by his equi-inclination beam method in which the axis of the cylinder and of the rotating crystal of the Weissenberg x -ray goniometer bisects, for a given layer-line photograph, the angle between the x -ray beam and the reflected ray. Buerger showed that the equi-inclination projection used in connection with photographs taken by this method has an advantage over the normal beam procedure because it requires only a single template for all curve forms and provides in addition straight lines for central lattice lines. The equi-inclination method was also shown by George Tunell to possess advantages in respect to the trigonometric functions involved in the intensity computations.

Thus far we have considered only three tools useful to mineralogy: the reflecting goniometer, the petrographic microscope, and x -ray apparatus. The field is too vast to do more than this in a short paper. The effort has been made rather to illustrate how progress in mineralogy has been dependent on the availability of suitable methods and instruments of attack; also that an instrument useful in one branch of science may prove to be equally serviceable in another field, if properly adapted to meet the conditions imposed in the new field. No attempt has been made to predict the applications of new methods, such as electron diffraction, or of new instruments, such as the electron microscope, to mineralogical problems. These must be gradually tested to ascertain their possibilities and their limitations before their usefulness in the field of mineralogy can be stated. We may rest assured, however, that mineralogy will continue to progress and that many discoveries important to mineralogy and to human welfare will be made by the mineralogist interested in research work in science.

PRESENTATION OF THE ROEBLING MEDAL
OF THE MINERALOGICAL SOCIETY OF
AMERICA TO ESPER S. LARSEN, JR.*

CLARENCE S. ROSS, *U. S. Geological Survey, Washington, D.C.*

The Mineralogical Society of America has given me the duty and privilege of presenting to you, Professor Larsen, the Roebling Medal as a token of its appreciation of your service to the Society and to the science of mineralogy. This duty is a pleasure; more fully so than commonly falls to one's lot.

The record shows that Esper Signius Larsen, Jr., is a graduate of the University of California, and received his doctor's degree from the same institution. After graduation, two years were spent in the Geophysical Laboratory, 14 years with the United States Geological Survey, and since 1923 with Harvard University as professor of petrology. You were a charter fellow of the Mineralogical Society, a councilor from 1923 to 1926, and president in 1928. A bibliography of about 100 papers on mineralogy, petrology, and geology includes the description of some 24 new mineral species.

The science of the microscopic study of rocks and minerals was founded by Sorby, and developed by such men as Zirkel and Rosenbusch; but you have placed your name with those of these great leaders by giving the petrographic microscope its fullest usefulness. Your careful determination of the optical properties of over 600 minerals, and the compilation of other data, led to the publication of a book entitled "The microscopic determination of the non-opaque minerals." The data it contains, giving the optical properties of all known non-opaque minerals, have made the petrographic microscope the supreme instrument of precise mineral determination, and this volume of yours must needs be a companion piece for every petrographic microscope. Thus, not only mineralogists and petrologists, but all who deal with crystalline materials—chemists, ceramists, and soil specialists the world over—have ever before them a reminder of the debt they owe to you.

Colonel Roebling would be happy to participate in the award of the Roebling Medal to you, for he aided in your work by placing at your disposal his unusual mineral collection, so rich in type materials. Thus you yourself experienced the generosity of Colonel Roebling, and I am sure that, again this day, you are deeply grateful to him; and in this we all concur.

Your other contributions have been mainly in the field of petrology, a

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sister science of mineralogy. The years while connected with the United States Geological Survey were devoted largely to the study of the San Juan region of Colorado and New Mexico, the largest area of volcanic rocks in the world which has been studied and mapped in detail. A long series of papers have resulted from this investigation, and similar studies are now being extended to other regions of the West.

Your work at Harvard University has been equally successful, where for 18 years you have continued to make notable contributions in both mineralogy and petrology. During that time, generations of students have received instruction from you, and you have given them a goodly portion of your enthusiasm and inspiration. You have been unusually successful in passing these attributes on to your students; no doubt a major factor in the notable success they have attained. You may well be proud of them as they are proud of having worked with you.

May I also say a word for myself. We have worked together in the laboratory with microscope by microscope, where I have seen your great volume come to completion. We have eaten camp fare together, traveled the mountain trails together, slept under the stars together, or listened to the complaints of sheep herders' proteges. We have traced lava flows and mapped boundaries together; in the laboratory or by the campfire we have had many discussions, some of them heated, but all of them friendly. Thus it is with a very personal feeling, and an intimate knowledge of your work that I discharge this pleasant duty here today.

And so, speaking for all groups here represented, in the name of the Mineralogical Society of America, I present you, Esper S. Larsen, with the Roebling Medal, given in recognition of exceptionally distinguished work in the field of mineralogy. May you have as great pleasure in receiving it as I have in placing it in your hand.

ACCEPTANCE OF THE ROEBLING MEDAL BY ESPER S. LARSEN

The chief and most cherished reward of a scientist is the recognition by his friends and associates. It was with great pleasure, therefore, that I received word that I was to be the fourth recipient of the Roebling Medal. I am truly proud that I have been placed with my three eminent predecessors. I am especially pleased that the presentation is taking place in my own city. I am deeply grateful to you for the pleasure and honor you have given me.

The Roebling Medal has an especial meaning to those who knew Colonel Roebling. I knew him less well than some of the former recipients of the Roebling Medal, but I had the pleasure of several visits with him and was much impressed by his great knowledge and love of minerals. He was most generous with his collections, and while I was accumulating data for my mineral tables he permitted me the free use of many of his rare specimens and the data on 110 rare species were secured from specimens of Colonel Roebling's great collection.

I have had unusual opportunities for my researches. I have always had much time and help for my work. I have been very fortunate in having the help, the counsel and the inspiration of many friends and associates. The inspiration and instruction of Professors Lawson and Eakle, and of Dr. Wood and later the kindly, patient help of our President, Dr. Wright, gave me an unusual start in my beloved work. At the Geological Survey I had the privilege of being associated for many years with Dr. Cross, one of our greatest petrologists. I also had the advantages of the help, counsel and friendship of Doctors Schaller, Foshag, Shannon, Ross, and Steiger. At Harvard I have had the privilege of association with Professor Palache, and from Doctors Berman and Hurlbut I have received much help and inspiration and have thus been enabled to keep somewhat in touch with the newer developments in mineralogy. I have been truly fortunate in my friends and associates.

My chief work in mineralogy has been on the optical properties of minerals and on the minerals in igneous and other rocks. The study of minerals under the microscope is fascinating, and it is remarkable that by this means one can identify a tiny grain and for many isomorphous groups can determine the approximate composition of the mineral. The mathematical interrelation between the various optical properties, their relations to the crystal structure, the density and the chemical composition of the crystal are marvels of natural law. The accuracy with which the properties can be rapidly measured is a tribute to the students of the subject. The three indices of refraction, or the three velocities of light for



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a biaxial mineral, can ordinarily be measured with an accuracy of a few parts in a thousand in less than an hour, or by Emmons' dispersion method with an accuracy of a few parts in ten thousand. All this can be done on one tiny grain.

The microscope has been used for the study of rocks and minerals for several centuries, but in the early days it was used simply as a magnifying instrument. The discovery and study of Iceland spar in the seventeenth century was the beginning of modern optical crystallography. At first Iceland spar was used as a toy by the ladies of the French Court, but a few scientists of the day studied its properties with great skill and diligence. Huygens worked out the ray velocity surface and many other properties of the mineral. No great contributions to the optical properties of crystals were made for over a hundred years. In the early part of the nineteenth century Fresnel and Arago studied the effects of superimposing plates of Iceland spar, formulated the laws governing interference in polarized light, and explained interference colors. Brewster studied crystals in transmitted polarized light and distinguished between isotropic, uniaxial, and biaxial crystals. The invention of the nicol prism by Nicol in 1829 gave us an easy means of obtaining polarized light.

In 1850 Sorby made thin sections of rocks by a technique not very different from that used today. Some thin sections had been made before Sorby's work. Zirkel became a student of Sorby and began an ardent study of rocks in thin sections. In the early years of this study it was considered a method for the study of texture only, and it was thought that minerals could not be identified in this way. However, within a decade Zirkel was able to identify the minerals of the rocks, and modern optical mineralogy had its beginning. Zirkel's work stimulated the microscopic study of rocks and minerals in Germany. Rosenbusch was one of the great early contributors. Tschermak studied many groups of minerals and gave us much optical data. In France, Foqué, Michel-Levy, and Des Cloizeaux contributed.

In 1870 Rosenbusch developed a polarizing microscope with a rotating stage for the study of rocks and minerals. Most of the instruments used in optical crystallography were invented in the latter half of the nineteenth century, and in that period the theory of optical crystallography was extensively developed. One of the most important of the instruments was the universal stage, described by a Russian, Fedorov, in a number of papers published in the last decade of the nineteenth century.

Up to the early part of the twentieth century minerals were studied under the microscope almost entirely in thin sections. They were recognized largely by sight and by simple tests such as relief, pleochroism, birefringence, extinction angle, and optical character. If a worker could

not identify a mineral, he sent the section to his friends, who might have found it in their work. The microscopes of that period would be considered almost useless by an elementary student of this day. Yet the identification of minerals by such men as Iddings, Pirsson, and Cross was remarkably accurate.

Minerals have long been studied by immersing them in liquids. In 1893 Becke proposed the method of central illumination for comparing the indices of refraction of adjoining bodies, and in 1898 Schroeder von der Kolk proposed the method of inclined illumination. These methods for the determination of the indices of refraction led to the systematic use of the immersion method. In 1894 Brun applied this method for the systematic study of minerals, and in 1898 Schroeder von der Kolk published tables for the determination of minerals by the immersion method. Wright was largely responsible for the introduction of the immersion method to America and he proved its great value in the study of minerals and synthetic products. While on the Geological Survey I found that the immersion method, taught me by Wright, was of great value in identifying the many specimens that came to me. At that time the books on optical mineralogy described only the rock minerals. I found so many minerals whose optical properties were not listed in the available books that I undertook to gather together for my own use all of the available data. This still left the data too incomplete for satisfactory use, so I undertook to measure the indices of refraction and other optical properties of the common minerals. With these new data there were fewer gaps than before, but still too many for entirely satisfactory use, and I felt compelled to secure optical data on as many of the recognized species as possible. In 1921 I was able to publish relatively complete tables for the systematic identification of minerals by the immersion method after I, and some of my close associates, had used the method for many years.

The recent development of the dispersion methods by Merwin and Emmons, and Emmons' use of the universal stage and the double dispersion method, have been great advances in the rapid and accurate determination of the optical properties of crystals. Indeed, Emmons' method for rapidly determining with considerable accuracy nearly all the optical properties of a mineral on a single small grain and in a single immersion is one of the great contributions to optical crystallography.

In the field of optical crystallography much has been accomplished in the last hundred years. Much remains to be done. Much more accurate and complete optical data, including such data as dispersion of the indices of refraction, are needed. Such data should be correlated with other mineral data and in particular with accurate chemical analyses. We especially need more data on minerals that show solid solution, as most

minerals do, so that we can determine more accurately the composition of a particular specimen. We have several hundred analyses with accompanying data on members of the amphibole group but this is not nearly enough to characterize the group. Few mineral groups or isomorphous series have been studied with sufficient detail and system. We need data on specimens carefully selected so that we can fill in systematically the many gaps that exist.

In conclusion, we can be certain that many very important contributions will be made in the next few decades but their exact character cannot be predicted.

SYMPOSIUM ON DIAMONDS*

(1) INTRODUCTORY STATEMENT

EDWARD H. KRAUS, *University of Michigan, Ann Arbor, Michigan.*

Mineralogists have always been interested in the use of the diamond for gem purposes. They have also known of the use of carbonado and boart in diamond drill bits. Relatively little attention, however, has been given by them to the very extensive use of the diamond at present in industry as a whole. The great speeding up of the defense programs in this country and Great Britain, and especially the interruption of the supply of wire drawing dies, formerly produced in the low countries and France, have created many difficult problems. Efforts were accordingly made to supply these deficiencies and also to accelerate the production of diamond-set tools and diamond-bonded wheels which are so vital in precision machining of metallic and other parts. In attempting to solve some of these problems manufacturers have quite naturally sought the advice of mineralogists. Their stock of the necessary technical information is quite limited due to the fact that only recently have a few mineralogists endeavored to correlate the practice of industry with our knowledge of the various physical and structural properties of the diamond. It was therefore thought advisable to arrange a symposium on diamonds to be conducted at the time of the meetings of the Mineralogical Society of America in Boston.

The program of the symposium included seven papers by persons especially competent in the fields assigned to them. The symposium attracted an interested group and provoked much discussion. Because of the large amount of valuable information contained in the papers, it was deemed desirable that they should be published together, and, as far as feasible, substantially as presented.

The paper on the production and supply of diamonds by Ball indicated the changes that have taken place in diamond production and that there is increased production in the alluvial fields especially in the Belgian Congo. Ball raised the question as to whether there are significant differences in the properties of the diamonds formed in the pre-Cambrian and those in the Cretaceous diamond pipes of South Africa. The present situation in the gem cutting industry was discussed in detail by Kaplan. The rapidly changing economic conditions naturally exert a great influence on the evaluation of gem diamonds.

The methods used in the production of diamond wire-drawing dies,

* Conducted as part of the program of the annual meeting of the Mineralogical Society of America, Boston, Massachusetts, December 30, 1941.

especially those of exceedingly small diameter, called superfine dies, as described by Herz, are most interesting. Indeed, it is a revelation to the professional mineralogist that it is possible to pierce a diamond and produce a hole with a diameter of only 0.0003" which conforms precisely to specifications. The efforts made by the federal government through the Office of Production Management to speed up the manufacture of wire-drawing dies in this country were described by Shayne, who reported that very material and satisfactory progress is being made to supply the need for some of the diamond dies formerly obtained from abroad.

Problems involved in the use of diamonds as tools for machining purposes were reviewed in considerable detail by Slawson, who stressed the need of more adequate scientific information concerning the properties and structural strength of the diamond on the part of the designer and the cutter of these tools. The progress made in this country in the production of bonded diamond wheels was reviewed by Klein. The type of diamond powder which has been found to be satisfactory for this purpose and the uses of diamond bonded wheels were described. The various properties which are important in the selection of diamonds, especially for industrial uses, were discussed by Berman, who advocated the close cooperation of mineralogists in an endeavor to determine satisfactory evaluation criteria.

It should be noted that this was the first symposium on diamonds dealing with many of their uses, that is, as a gem and in industry, that has been held. In view of the interest taken in the symposium and the valuable information which has been gathered, it is hoped that a similar program may be arranged for the next annual meeting of the Society.

As chairman of the symposium, I desire to express my sincere appreciation for the enthusiastic response and cooperation of those who were invited to participate in the symposium, and to the officers of the Society for making provision for the session. Our thanks are also due to Mr. Harvey B. Wallace, President of the Wheel Trueing Tool Company of Detroit, and to the Norton Company of Worcester, Massachusetts, whose financial support has made the publication of the papers possible.

(2) DIAMOND PRODUCTION

SYDNEY H. BALL, *New York, N. Y.*

The diamond occurs as a mineralogic curiosity in a large number of places on every one of the continents, but its commercial occurrences are few. The first discoveries were made in India, perhaps 800 to 600 B.C., and India was the dominant producer until the rich Brazilian fields supplanted it late in the second decade of the 18th century. Brazil, in turn,

lost the lead to South Africa about 65 years ago. Since, then, the story of production has been mainly an African one. Prior to 1909, the Union of South Africa was, from a practical standpoint, the only producer, but since the latter year diamond production has undergone one of its major cyclical changes. From 1907 to 1930, important alluvial diamond fields were successively found in the Belgian Congo, South-West Africa, Angola, Gold Coast and Sierra Leone. These virgin fields are, on the average, rich and have low operating costs, and their production has grown with astounding rapidity.

South Africa held the lead, as to value produced, up to 1936, but now its pipe mines are shut down, due to economic factors within the industry, and its alluvial production is slowly decreasing.

Production today is, by weight, about 14,000,000 carats (slightly over three short tons), worth some \$35,000,000, as opposed to an average of 7,200,000 carats, worth about \$75,000,000 for the four years 1927 to 1930. The change is mainly due to the large boart production of a single Belgian Congo company, Beceka, which in the past two years, by weight, has accounted for over one-half of the world's production. As a result of this shift in production and the shutting down of the pipe mines, the weight of fine cuttable material produced today is but 60% of that of a dozen years ago, cuttable goods making up about 55% of the 1927 production and but 16% of that of 1940.

If the war continues, the 1942 production will be less than that of 1941, since the larger producers of today are situated far from sources of supply and some of them must soon become short of certain essentials. Indeed, a year or two hence may well see some of them shut down through lack of supplies.

At present the Belgian Congo is the largest producer accounting for 75% of the world's production by weight and 25% by value. It is followed by Angola and Sierra Leone, the Gold Coast and Brazil, and the alluvial fields of the Union of South Africa. The British Empire produces about 25% by weight and somewhat less than 50% by value of the total. Brazil in the recent past has increased its production appreciably, the major portion of which is now purchased by the United States Government. British Guiana and Venezuela add their pittance. The Western hemisphere, however, by weight, produces but three per cent of the world's production, and by value, something less than 10%.

This change in production is not only geographic; it is also one of the geologic age of the rocks which are the source of the diamond. The best known diamond occurrences, to the layman and scientist alike, are the South African kimberlite pipes, intrusives of Cretaceous age. While the Union of South Africa pipes, those of Kimberley and that of the Premier

Mine near Pretoria, are most frequently mentioned, similar intrusives occur in South-West Africa, Rhodesia, southeastern Belgian Congo and Tanganyika Territory. The diamond content of the kimberlite of these other countries is, so far as we know, however, non-commercial. In passing, it may be stated that the Arkansas kimberlite intrusives near Murfreesboro are also of Cretaceous age. The alluvial diamond deposits of the Union of South Africa, South-West Africa and Tanganyika Territory are derived, in large part at least, from the erosion of kimberlite pipes.

Some of you will remember that an occasional diamond—usually green in color—is recovered with the gold of certain of the Witwatersrand gold mines. These diamonds occur as pebbles in a pre-Cambrian rock. The Belgian Congo diamonds are known to occur as pebbles in Jura-Triassic rocks and at least one stone was washed from a sheared basic igneous rock, a member of the pre-Cambrian basement, below the flat-lying Jura-Triassic rocks. While it must be admitted that possibly a native helper of the geologist who found the stone, knowing what his boss wanted to find, salted him, the evidence is fairly conclusive that the Kasai diamonds are derived from pre-Cambrian rocks. Further, N. R. Junner reports that the precious content of the Gold Coast alluvial deposits is derived from pre-Cambrian rocks. Indeed, diamonds have been recovered from the clean-up of the Ashanti-Adowsena gold mine, the ore bodies of which occur in the Tarkwaian quartzites of the Banket series of pre-Cambrian age. The important Sierra Leone alluvial deposits and those of the French African colonies likewise are, with little doubt, derived from pre-Cambrian rocks and the Gwelo Forest, Rhodesia, deposits may be.

Thirty years ago practically all diamonds produced came directly or indirectly from Cretaceous pipes. In 1940, due to the limited scale of pipe operations, 96% by weight, and 72% by value of the African production was obtained from gravel deposits from pre-Cambrian rocks.

This change in production is also one of mining methods; and probably never before has a mining industry, after fifty years of dominant lode mining, become mainly an alluvial mining industry. The switch is one from a few large up-to-date units (the Premier Mine before the first World War was the largest tonnage mine in the world) to a large number of relatively small plants, most of which are well run. The condition seems atavistic, but there it is!

The lesser amount of cuttable and the greater amount of industrial diamonds produced today coincides with a change in the consumption due to the remarkable increase in the use of industrial diamonds; eight-fold in the past 25 years. This year the United States alone will consume over 3,000,000 carats of industrial stones. Now over 75% of the world's rough diamond sales, by weight, and one-third by value, are of industrial

stones. Today, in part due to the world war, managers are learning the necessity of the use of industrial diamonds in factories, and artisans by the thousands are being trained in their use. We can confidently look forward to further increases in the future; and ten years hence, don't be surprised to see underground drifts being drilled with diamond drills and not by percussion drills.

While war has increased the use of industrial diamonds, it has also somewhat restricted the market for gem stones. The United States, Canada, South America, and the East are buying more than their normal quotas of gem stones, but the war has practically stopped sales elsewhere. Further, the destruction of the cutting industries of the low countries has brought about a distinct shortage in the supply of small cut for mountings and no too abundant supply of large fine cut.

At present industrial diamonds, except in the case of Beceka and the carbonado alluvial deposits of Bahia, are by-products of gem mining. In the future, if the price of industrials continues its rise, more deposits may find industrials their dominant product.

You may be interested as to guesses regarding reserves. The pipe mines have blocked out reserves of the order of some five years' mining at normal rates, and the alluvial fields of some ten years. The reserves to be later blocked out may equal another ten years. In short, it is believed that the total reserves of diamonds are of the order of those of lead and zinc and much less than those of copper.

In closing, may I add that the three tons of diamonds require some 70,000 men to produce them, of whom 8,000 are Europeans: each man labors a year to produce 1.4 ounces of diamonds: and in the gem mines the production is but 0.425 ounces per man year. About 40,000,000 units of gravel are mined and milled to produce one unit of diamond. It is always a marvel to me how the mills are able to seek out that one-forty millionth.

(3) CUTTING OF GEM DIAMONDS

LAZARE KAPLAN, *New York, N. Y.*

Before the invasion of the low countries, our source of supply of polished diamonds was Belgium, Holland, and Germany, where approximately 95% of the world's supply of polished diamonds was produced. We, here, had the choice of either making our purchases by personally traveling to Belgium and Holland, or placing our order with a buying representative there.

To illustrate the vast difference between the amount of diamonds cut in these three countries and the United States, in the period preceding the invasion: there were about 40,000 diamond polishers in Holland,

Belgium, and Germany (and about 1,000 in France, England, and the Transvaal), as compared with about 250 diamond polishers in the United States.

The following table will serve to illustrate the large quantities of unset cut diamonds which the United States imported from the years 1936 through 1940:*

<i>Year</i>	<i>Carats</i>	<i>Dollars</i>
1940	321,499	\$22,009,943
1939	488,154	27,417,273
1938	330,925	17,016,842
1937	517,677	29,860,396
1936	445,610	22,707,703

Cutting in Europe was geared for quantity production and probably about 75% of the men worked on small stones ranging from 10 to the carat down to the smallest sizes. There were large institutions in Belgium (similar to schools) which did not actually manufacture their own merchandise but took in piece-work on a very large scale. A similar arrangement was operating under government control in Germany, showing the desire of the German government to encourage the diamond-cutting industry there. The German manufacturers did not cut their own merchandise but contracted to cut rough stones supplied by Dutch and Belgian merchants which they produced on a piece-work basis. Thus, the German cutters had no merchandise for sale. When necessary, the German government even granted subsidies to cutters to enable the industry to reduce its labor costs to a level that would induce the Dutch and Belgian merchants to send their work to Germany instead of doing the cutting in their own countries. The principal article cut in Germany was single cuts. (A single cut is a small round diamond of eighteen facets: one table, eight facets on top, eight facets on bottom, and one culet.) In Belgium, the system of homework was practiced, which the government tried to abolish and did succeed in reducing.

With the attack of the Germans on Belgium and Holland, the source of supply of polished diamonds officially or apparently ceased. Refugees began to arrive in the United States in great numbers, bringing with them large stocks of polished diamonds from Europe. Yet, notwithstanding the stoppage of cutting in Europe, we find large quantities of polished diamonds being imported from various countries into the United States. These came into the United States via round-about routes through France, Portugal, and the South and Central American countries. Thus, the shortage that was expected at the time of the invasion was less than anticipated.

* From "The Diamond Industry (from 1936 to 1940)"—by Sydney H. Ball.

To explain these importations, one must take into consideration the fact that for some years diamonds had been sent to this country and placed in a Bonded Warehouse, which meant that these diamonds had not actually been entered as importations nor had duty been paid. This system of entering diamonds in a Bonded Warehouse was greatly facilitated by the U. S. Exhibition Act which permitted diamonds to be exhibited here, pending sale or return, under the custody of the Warehouse, without payment of duty. Duty was only paid upon actual entry of merchandise. By chance, the New York World's Fair prevented a very large and valuable stock of both rough and polished diamonds from falling into the hands of the invaders, since many large European firms (including the Diamond Trading Company, Ltd. of London) had exhibitions at the Fair of merchandise entered here under the Exhibition Act and which had not as yet been returned to Europe when the invasion took place.

Thus, at the outbreak of the war in Europe, there were many diamonds in the Bonded Warehouse pending the time when the owner wished to make the formal entry, and pay the duty. Since then, these diamonds have been taken out of the Warehouse and considered as importations, so that figures of importations do not show an accurate picture of what actually came from Europe since the war. From Customs Reports we find that the United States imported from Belgium in the month of September, 1941, a total of 12,079 carats of polished diamonds, of which 8,321 carats actually came from stocks in the Bonded Warehouse. Thus, in reality, 3,758 carats were transferred from Belgium to the United States in that month. And, if we try to break down that 3,758 carats, we find that some of it may have been brought over by refugees.

The refugees claim that the diamonds they bring with them are from their old stocks in Europe. However, it seems reasonable to believe that these stocks would have been exhausted by this time. It appears more likely that the emigrant is seeking to conceal the fact that there are diamonds being cut now in Germany and in German-controlled countries which the emigrant purchases and brings with him to this country via round-about routes.

Until recently, cutting in the United States was mainly quality production. The work was superior and the "art" of cutting diamonds was practised with the main emphasis placed upon the quality of the work produced. However, with the advent of the newcomers, the European methods of quantity production are being introduced here.

Most of the American diamond cutting up until 1939 had been done in New York City where the majority of the 250 cutters were employed. Now, however, cutting has spread to many points outside of this city, such as New Jersey and Pennsylvania. Instead of the original 250 workers

we now find about 1,000 good mechanics and about 800 apprentices in this country today. This increase is mainly due to the recently-arrived Europeans who are very enterprising. Many of them opened up diamond-cutting shops here. Others entered the employ of American cutters who now found it necessary to increase their staffs to meet the great demands being made upon American cutting. In addition to the new shops and the new European emigrant workers, the system of apprentices is becoming popular here. As a matter of fact, one refugee induced the town of Hazleton, Pa., to build a factory for diamond cutting without cost to himself, where local boys are taught to cut single cuts.

In Europe, before the invasion, diamond cutters earned between \$5 and \$15 a week. During the same period in this country, diamond cutters earned between \$50 and \$75 a week. However, the American cutters were all fine mechanics and quality-workers. The best of the European workers came here to benefit by the higher wage scale. Since the invasion, however, a man producing the equivalent of the European who made \$5 to \$15 is today making from \$100 to \$250 a week here for a 35 hour week. (In Europe there was a 40 hour week). The reasons for this tremendous increase in wages are:

(1) The American standard of living and the American diamond cutting wage scale have always been higher, as shown by the fact that we were paying from \$50 to \$75 a week before the war.

(2) Cessation of European cutting placed a great demand on the American manufacturers and thus created a great demand for cutters.

(3) Shortage of trained cutters here caused manufacturers to outbid each other for workers. Added to this, the demand of the newly established shops made the shortage more acute.

(4) Union policy and union standards.

The union calls itself the "Diamond Workers Protective Union of America" and it tries to be "protective" to its members in every sense of the word. It did not allow any apprentices to enter the industry in the past thirty years and followed the idea that the fewer the workers, the higher the wages and the steadier the work. Through this short-sighted policy, the industry was almost choked, and we find that the average age of the union member in 1939 was about 57 years.

Because of the new shops that were being established outside of the union and the acute demand of the shops for diamond cutters, the union felt it was losing control of the situation and finally decided to change its policy and admit new members and apprentices.

Today, there are 650 full-fledged members of the union who are expert workers, which is an increase of 250 in one year. The emigrant workers account to a great extent for this increase. There are also 400 apprentices in the union today, all of whom are new members since last year.

After the union passes upon an apprentice, it places him with a manufacturer. As an apprentice, he receives the starting wage of \$3.00 per week and advances to \$32.00 a week in three years. As the first part of the apprenticeship wage is below the Federal Minimum Wage provisions, this is done with the special consent of the Department of Labor in Washington, as the government recognizes the period of training for diamond cutting to be three years. The apprentice wage scale follows:

\$3.00 per week for the first three months.

Increase of \$1 per week each month for the next 29 months.

At the 32nd month, he receives \$32 weekly, which continues through the 36th month.

After his apprenticeship is completed, the apprentice is given a trial period and his future salary is based upon his production. There are also some shops employing non-union labor and we figure that there are about 750 workers in these shops, of which about 400 are apprentices.

As we can see, the tremendous increase in the cost of labor played a very important part in the increase of prices of diamonds. In addition to this great advance in wages, the cost of materials, machinery, rent, and incidentals, all of which have always been considerably higher than in Europe, have increased as well. The Diamond Trading Company, Ltd. of London made a number of raises in the price of rough diamonds amounting to a total increase of about 25% since the invasion of Holland and Belgium. All of these factors can account for the increase of diamond prices.

However, large stones have and always will be profitable to cut in the United States as long as rough material is permitted to enter the United States duty free, and polished diamonds are subject to a 10% duty when imported. Consequently, the American cutter is immediately protected by an advantage of 10% which serves the same purpose as a subsidy. However, on smaller stones from $\frac{1}{4}$ of a carat down to the smallest sizes, the cost of American labor was and is so high per carat that the 10% advantage was not sufficient to enable the cutter to meet European competition.

In Europe, before the war, the cost of production of a single cut diamond was about 15¢ a stone. Here, however, the cost of production of the same stone is about \$2.00. Thus small stones have so pyramided in price today that the demand for them is reduced. Jewelry manufacturers are cooperating very sensibly by eliminating the use of small stones from designs as much as possible. Otherwise, small diamonds would probably be much higher than they are.

Therefore, a very unusual situation exists today. Small diamonds from about 20 to the carat and smaller are at a premium at present. Whereas ordinarily, these stones would cost much less than the medium sizes (from $\frac{1}{3}$ of a carat to $\frac{1}{2}$ of a carat), today they have equalized or surpassed

the price per carat of the medium size diamonds. Therefore, persons buying the medium sizes today are receiving much better value. In diamonds above $\frac{1}{2}$ carat, the price increases have been even less, in proportion. Thus, in buying a diamond today, persons purchasing the larger sizes (from $\frac{1}{2}$ carat and larger) are receiving the best possible value.

In view of the facts presented we naturally wonder what is likely to happen when conditions return to normal. Will the American manufacturers of small stones be able to compete with the European manufacturers under normal conditions? In view of the wage situation, it seems very unlikely. Then, too, it is interesting to recall that after the first World War, the Belgian government reduced taxes in order to bring the diamond industry back to Belgium. I would not be surprised if governments such as Belgium and Holland would make similar arrangements after this war to encourage diamond cutting, particularly in the smaller sizes. However, as far as larger sizes are concerned, we feel confident that the United States cutters will always be able to continue to increase and to improve their production. Industries in the United States have always expanded and progressed with the times and we feel certain that the diamond industry will not be an exception. Today, the diamond industry is being called upon to be of service to this country in producing shaped diamonds for tools which are so vital for war materials. As a matter of fact, in our factory in Puerto Rico, we have already begun to cut special shaped industrial diamonds for these tools and are looking forward to increase our service to our country.

(4) DIAMONDS IN THE WIRE DRAWING INDUSTRY

PAUL L. HERZ, *New York, N. Y.*

Diamonds are used extensively in the drawing of wire in sizes from 0.080" in diameter (the size of a knitting needle) down to the finest made, 0.0003". The wire is drawn through a tapered hole drilled into the diamond. Because diamond is the hardest known material and because it will take a high polish, smooth wire can be produced at high drawing speeds.

Up to fifty years ago steel draw plates or ruby or sapphire dies were used for drawing fine wire and it was necessary to draw the wire slowly. Because the dies wore rapidly, increasing the size of the hole, it was difficult to produce accurately gauged wire. In later years tungsten, molybdenum, and boron carbide dies have competed with diamond dies. Diamonds, however, enjoy an exclusive field for the harder and tougher wire materials such as chrome-nickel resistance wire, brass and phosphor bronze wire, and high carbon steel wire. Diamond is also used for drawing

electrolytic copper wire from the smallest sizes up to diameters approaching 0.080". In addition, diamond is indispensable wherever precision of size and perfect roundness are essential considerations. Gold, silver, and platinum wire for ornaments and, in general, all wire which is to be woven into metallic cloth is drawn through diamond dies.

There is a borderline field in which diamond encounters stiff competition with the ever improving sintered carbide dies, for example, the larger diameters of copper wire, or the medium size common steel wire. Here the choice of die material is governed by economical and practical considerations. The larger the diameter of the wire the larger must be the diamond, and the economical limit is reached when the cost of the stone is excessive. From the practical standpoint the drawing force increases sharply with the increase in the diameter of the wire. A kink in a fine or soft wire will straighten itself out when passing through the die but a thick tough wire will crack the diamond under similar conditions.

About fifteen years ago, wire drawing engineers thought that the newly developed carbide dies would replace diamond dies for the drawing of copper wire. Subsequently the diamond dies were improved principally by using smaller high grade diamonds instead of a large poor quality stones, and the diamond soon regained its supremacy in the copper wire industry.

There are no statistics available giving the quantity of diamonds used in the manufacture of dies. As a producer of dies, I have made a continuous effort to collect information on the manufacturing activities of die makers in every country and on the production of wire in various plants throughout the world. These data were corrected from year to year up to 1939, and I estimate that in normal times the consumption varies between 175,000 and 225,000 stones weighing from 50,000 to 60,000 carats. The manufacturing and maintenance (resizing) of these dies required the crushing into powder of between 100,000 and 110,000 carats of low grade diamonds.

The question has been raised as to the possibility of new materials being produced which will supersede diamonds in the wire drawing industry. It has been hoped that a new material might be developed which combined an equal molecular cohesion (hardness) with a superior resiliency. In the field of small size wire in which the use of diamond dies is now confined additional resilience is not necessary. There seems to be no reason for assuming that a material of equal hardness, which is the greatest asset of a die material, can be developed. I entertain little hope for a new synthetic material to match the close-packed, tenaceous, and fine grained structure of the diamond. I believe that diamond has a brilliant future in the die industry because the normal trend of the in-

dustry is towards harder and tougher wire as well as higher drawing speeds.

In the diamond die industry dies with openings between 0.010" and 0.001" are referred to as *double naught* dies and those of smaller sizes as *triple naught*. These small dies are especially difficult to manufacture.

The drilling is done by means of a steel needle charged with diamond powder mixed with oil which grinds a tapered hole in the diamond. The diamond must undergo some processing before being drilled. First, two parallel flats are ground upon the stone. Then a deep entrance cone is cut into one of the flats and the stone is ready for drilling.

A steel needle is inserted into the hollow chuck of a horizontal drilling machine, Fig. 1, and secured with shellac. An alcohol flame keeps the shellac plastic while the chuck revolves and the needle is then centered by touch. The centering operation must be so synchronized with the hardening of the shellac that the needle is perfectly centered and its tip revolves without whipping when the shellac has become hard. The needle is then ground to the required taper by means of a portable grinder.

The diamond is then attached to the holder which is free to move back and forth while it rests upon rollers. The cement is allowed to harden after the entrance cone of the diamond has been brought into alignment with the axis of the needle. The drilling is accomplished by oscillating the diamond against the rapidly rotating needle. During the process the operator will have to recharge the needle with diamond dust and regrind it as it wears and also reshape it to suit the pattern of the required profile.

When the hole has been drilled to about $\frac{3}{4}$ of its depth it is centered upon a spotting machine, Fig. 2, for counter drilling. The chuck plate which is removable is inverted and a conical indentation is ground upon the other side of the diamond so as to meet the hole previously drilled in the stone. This is a delicate task for the operation is done blind and the back cone must be exactly in the axis of the drilling and entrance cone. When an opening has been made through the stone it is ready for polishing.

In the polishing machine, Fig. 3, the diamond, as well as the needle, revolves. The stone is on the chuck and the needle is on the holder which plunges back and forth in the drilled hole. The purpose of this is to bring the die to size and give the drawing canal a high polish.

There are many different types of polishing machines. Some use a wire and a longer stroke instead of a needle. Another is vertical with the stone revolving horizontally and the in- and out- stroke of the needle is combined with a side rocker motion which rounds off and polishes the entrance as well as the outlet of the die.

A vertical drilling machine is likewise in use especially for drilling the

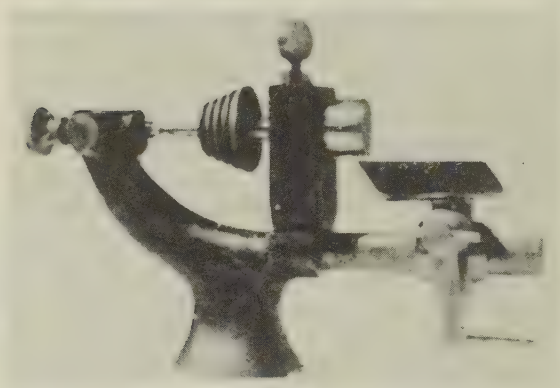


FIG. 2

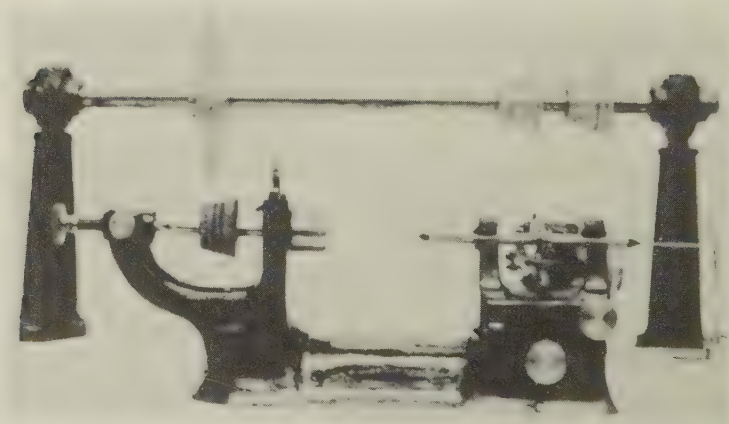


FIG. 3

larger size dies. The needle for larger dies may be sturdier and may oscillate more violently so that a large hole may be drilled as rapidly as the medium sized ones. With the very small dies the needle is no longer rigid, and the difficulties increase immeasurably so that the working skill and time required are much greater.

What are known as capillary dies range from 0.0012" down to as low as 0.0003" in diameter. Hitherto all capillary dies were imported into this country because the high labor costs made their manufacture in this country unprofitable, notwithstanding a 30% protective tariff. Yet we now need fine capillary dies for the making of many essential defense items.

Capillary dies must be drilled with a needle so fine that it no longer has any rigidity at the tip. On the ordinary drilling machine, Fig. 1, the diamond may be stuck and centered onto the holder with the drilling needle itself. With dies of capillary size it is impossible to center anything of any weight with such a fine needle. No matter how small the diamond may be, its weight is considerable. In order to overcome the difficulty of aligning the stone in the axis of drilling with the needle, the stone is no longer cemented onto the holder but is simply stuck with oil or vaseline so that it can float freely and center itself.

It takes many years to train skilled labor for this work. Few qualify because it takes special aptitudes to become a successful fine die driller. Good eyesight, calm nerves, the faculty of concentrating on and judging small distances and, particularly, a fine sense of touch without which you cannot center a needle or a stone properly. When the drilling needle is not centered to perfection and thus whips at the end, the time of drilling mounts rapidly and the hole drilled is neither round nor as small as you set out to make it. In other words consummate skill is required to drill a triple naught die and anything short of that skill produces defective double naught dies instead. It takes a skilled man an average of 130 to 200 hours to produce a capillary die and he cannot guarantee when he starts that he will turn out, let us say a 0.00042" die. He can only say that he will start simultaneously drilling four or five stones, striving for 0.00038" in the hope of getting one or more 0.00042" in size.

(5) DIAMOND DIES IN THE NATIONAL DEFENSE PROGRAM

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In October of 1940, the Advisory Commission to the Council of National Defense, in the pursuit of its general policy of providing the United States with an adequate and steady flow of vital and strategic materials, made an extensive survey of the diamond die industry in this

country, and found that with the exception of the limited output of a group of three Frenchmen resident here, no dies below 0.004" were manufactured here, but that all such fine dies were imported. It was found, moreover, that the capacities of the manufacturers of these large sizes were limited and considerably below the demand then existing and far under the expected future requirements.

In view of the cutting off of imports from Europe, and in view of the fact that the diamond die was a particularly important factor in the drawing of wire destined for the manufacture of very many products vital to national defense, the Advisory Commission embarked upon a program of collaboration with the existing diamond die manufacturers in a concerted effort for the expansion of their facilities and for the acquisition of the intricate and difficult art of drilling the smaller-sized dies.

Considerable difficulties of a technical and time-consuming nature were presented in the transplanting of such an industry to the United States—an industry which had been slowly and painstakingly developed in Europe over a period of generations. Hence the newly-created Office of Production Management set up several avenues for the purpose of ensuring to the wire drawers of the United States uninterrupted sources of supply for the dies they required. We enlisted the aid of the British Diamond Die Controller, and through his close and valuable cooperation, it has happened that at no time have our wire drawers experienced any severe shortage of the necessary dies. By very close cooperation with our American diamond die makers, their production began to increase as to large-sized dies, and before many months had passed, six concerns which had never before drilled dies below 0.004" were in actual production of 0.001" dies. Today, these six manufacturers are producing, in small quantities, dies below 0.0008"! In one instance in particular, a perfect die below 0.0004" was achieved. Most of the diamond die concerns succeeded in drilling dies down to 0.001" without any financial aid on the part of the government.

OPM took upon itself the task of gathering all available information and studying the technological processes of the art of drilling fine dies, and thereupon disseminated it among those manufacturers who were eager to acquire the knowledge necessary for the manufacture of these dies. This active participation of OPM in the solution of the problem has been one of the chief factors contributing to the present output of fine dies, which, although limited as to quantity, approximate in quality the dies previously imported and sought after by the wire drawers. The wholehearted willingness of the diamond die manufacturers to risk their time, their money and their effort in the long-drawn-out experimentation also contributed substantially. Most of the firms which have proved

ability to produce dies below 0.0015" have now received, or are about to receive, financial aid from the government for the expansion of their present facilities and for the expenditures entailed in the training of new personnel. This last step is expected to accelerate production of fine dies and quickly bring it to the level of our total demands, which have increased considerably within the past several months and threaten to increase still further. As a matter of fact, the total consumption of fine dies between 0.0004" and 0.002" inclusive is presently at the rate of over 600 per month, and is expected to reach well over 1,000 by February, 1942.

The major problems facing OPM and the diamond die manufacturers in the clarifying of the requirements for the production of fine dies were:

- (1) the selection of personnel with definite aptitudes;
- (2) the grinding of the needle to proper shape and size;
- (3) selection of proper diamond powder for drilling;
- (4) mounting of the stone for drilling;
- (5) amplitude and intensity for the reciprocating action of the member carrying the stone to be drilled;
- (6) ability to observe by means of optics the drilling operation of the stone while in progress; and other practical considerations, such as speeds of the needle, prevention of vibration, etc.

The British Diamond Die Controller had produced a drilling machine embodying the solution of practically all of the requirements just mentioned, and OPM succeeded in arranging for the bringing to this country of a model machine together with the pertinent drawings and technical data concerning its use and operation. The principle of this machine has been discussed on several occasions with the group of manufacturers engaged in drilling fine dies; the machine has been exhibited to them, and considerable guidance has been furnished as to how the principles incorporated in the machine can be adapted to the existing horizontal-type machine in use here. Several copies of the new-type machine are presently being manufactured and will no doubt be in operation before this paper is read. Only last week, under the auspices of OPM, these new machines were set up in a demonstration model shop for the benefit of those diamond die makers who have succeeded in drilling dies below 0.002" and who are judged capable of utilizing the new machines to the fullest extent.

Moreover, in attempting to determine the desirable speed of the needle in the drilling operation, speeds were used from 4000 RPM up to over 200,000 RPM, and it was ascertained from these experiments that approximately 6,000 RPM is the most practical and desirable speed.

Some manufacturers have succeeded in developing a practically au-

tomatic machine for drilling dies down to 0.002" in mass production, and these machines are being used at the present time. The training of operators for these machines is a matter of only a few weeks.

At the instance of OPM, a mineral oil has been developed and perfected which has been found superior to the olive oil formerly employed, and it is now being used by many in the industry with very satisfactory results.

For the time being, consideration has not been given to either the type of stone selected for drilling, or the direction of the drill hole in reference to the crystallographic axes.

One of the most difficult problems in drilling dies is the back-piercing operation. The larger the die, the simpler the operation. For extremely fine dies, however, the back-piercing process is a difficult one. Usually, when the die is drilled from the entrance end, after the stone has been drilled to approximately two-thirds of its depth, the drilling of the remaining third is accomplished from the opposite end. The British Diamond Die Controller has developed for this operation a special device based upon optics and other mechanical contrivances, which enables the operator to center the die with great precision so that the axis of the back-piercing is coincident with the axis of the portion already drilled. This machine, too, has been made available in this country, and promises to be equally important.

The new technique of drilling triple-0 dies now at the disposal of our diamond die makers promises to obviate still another formidable handicap—that is, the training of new personnel. This has been considerably simplified, and it is our belief that properly selected operators can be trained to become skilled and expert within three months, as opposed to the many years of experience required by the European method.

The program described will definitely assure a more than adequate supply of manufacturing facilities and trained personnel for the satisfaction of the needs of American wire drawers, and will render this country independent of any outside source of supply.

It may be of some interest to present some of the data which has been obtained through the studies and experimentation so far conducted.

(1) The needle for dies below 0.002" must be approximately 2 microns smaller than the die to be drilled. The drilling needle is made of the ordinary needle rod, and receives the same heat treatment as the ordinary sewing-needle.

(2) If the pressure or impact-force to be exerted by the tip of the needle is not to exceed 75,000 pounds per square inch of projected area, then for a 0.002" needle a pressure up to 3.8 ounces should be applied. For a 0.0003" needle, the pressure should not exceed 0.083 ounce.

(3) It was observed that for a needle approximately 0.0005" in diameter, the wearing away of its length was 0.0015" per hour, while the drilling of the diamond stone progressed at the rate of 0.0001" per hour.

(4) (a) The natural frequency of vibration of the entire system must be below the operating speed of the spindle.

(b) With a needle approximately 0.020" in diameter, having a freely exposed length of 1 inch, the natural frequency of vibration of the needle will be about 30,000 RPM.

(c) If the tip of the needle is 0.0003" and the included angle is at least 10 to 12 degrees, the natural frequency of vibration of the tip will be considerably higher than that of the main body of the needle.

(d) The needle which was successfully run up to 200,000 RPM (by means of a small air-turbine) was 0.016" in diameter, was exposed $\frac{5}{16}$ of an inch in length, and held in a babbitt bearing.

(5) With the conventional French-type horizontal drilling machines, out of every 100 dies to be drilled to 0.0004" size, only 3 per cent are obtained of the proper size, while the balance go in increasing percentages up to 0.002". With the microscope attached to the drilling machine produced by the British Diamond Die Controller, the operator is not only enabled to shape the needle to the proper size and then watch the progress of the drilling itself, but he is also equipped with means of making accurate measurements of the shape and diameter of the hole being drilled, since there is a scale on the eye-piece divided into spaces equalling 0.0004". In this manner about 80 per cent of the dies are drilled to proper size.

(6) The diamond for fine dies is usually about $\frac{1}{5}$ of a carat, having a total height of 0.06". The top and bottom are ground parallel. On the side a window is ground for observation purposes. The preliminary drilling is done on a machine designed to take large impacts; the fine drilling is done on the British machine mentioned previously. To obviate the necessity of centering the stone in absolute line with the needle, the stone is held by a lubricant (vaseline) between the stone and the surface to which it is attached. Proper grading of diamond powder is most essential and particles under 3 millimicrons should not be used, since they have no cutting properties.

(6) DIAMOND SET TOOLS

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In previous papers (1) presented before this Society the variation in hardness in the diamond with direction has been discussed. Because of this variation in hardness it is possible to cut and polish diamond crystals with diamond powder as the abrasive. It is also possible with the aid of

another diamond to make a slit in the surface of the diamond into which the edge of a cleaving iron is inserted to cleave the stone. However, the direction of least hardness within a diamond is so much superior to the hardness of any other known substance that the question of the absolute hardness is dismissed for the purpose of this paper with the statement,— *because of its superior hardness diamonds possess the ability to readily cut all other known substances.*

It is proposed further to limit this discussion to shaped diamond tools whose contour conforms to specifications. These tools are formed from single crystals of the better grades of industrial stones. They are commonly used in two ways. First, to cut a predetermined contour into the material being worked; second, to cut a contour into the face of a grinding wheel which in turn is used to grind into the material a shape which is identical to the shape of the diamond tool.

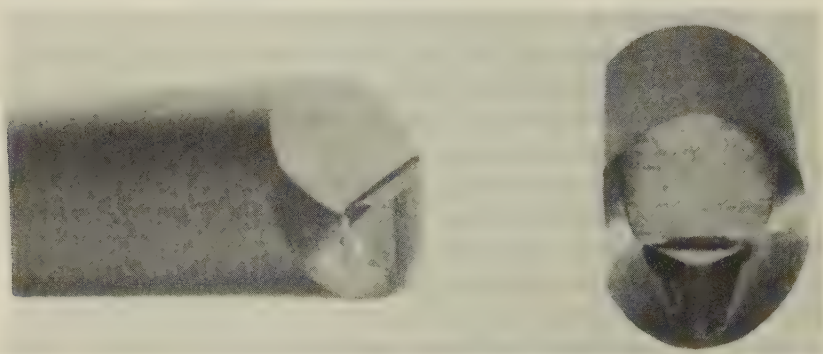


FIG. 1

The second method has been expanded into one in which a diamond point, following a templet, moves across the face of a grinding wheel and cuts into the face of the wheel a contour which is identical to that of the templet. The grinding wheel is then used to transfer the reverse of the same contour to the object.

In shaping a diamond crystal to conform to the specifications of the tool designer a knowledge of the variation in hardness with direction is necessary. Not only is a knowledge of the direction of least hardness necessary, but also the sense of that direction. In the cutting of gem diamonds certain empirical methods have been formulated which experience has shown to be the best direction for cutting facets. Because these facets are symmetrically disposed and have standard angular relationships to each other there are only a few fundamental cutting directions that must be known.

Although most diamond cutters use empirical methods in cutting gem stones, they are also familiar with the "grain." In the sense in which it is used by diamond cutters "grain" does not refer to the internal characteristics of the stone but to certain external growth markings upon natural crystal faces. The favorable direction of cutting is perpendicular to these markings. In most instances the cutter will know, too, the sense of this direction, but if not, it can readily be determined by trial and error. There is also, in many instances, a choice between two favorable directions one of which is markedly superior to the other.

Unlike gem diamonds the shapes of diamond tools are not limited to a few standard forms. Special operations call for tools with not only flat surfaces at certain definite angles, but also curved surfaces with specific radii of curvature (Fig. 1). A more thorough and fundamental knowledge of the variation of hardness with crystallographic direction is needed to shape diamond tools than to cut gem diamonds. One highly trained man can, however, direct the work of cutters who have the requisite amount of mechanical skill.

But of even more importance is the fact that this knowledge of hardness must be supplemented by a knowledge of the other physical characteristics. It is only possible to take full advantage of the superior hardness of the diamond and utilize its cutting qualities *when the cutting edge is so disposed that the diamond is least apt to rupture under strain.*

The ability of the diamond to resist rupture has been termed "structural strength." The structural strength of a non-crystalline substance is dependent upon its resistance to fracture alone, but in crystalline material gliding, parting, and cleavage may also play an important role.

The apparent fracture surfaces which occasionally appear upon diamond crystals are found, upon microscopic examination, to consist of a series of step-like cleavages. All evidence seems to indicate that fracture, as the term is used on quartz, does not occur on the diamond.

Nor is there any evidence of gliding in the diamond and the parting that may accompany it. The twinning that is observed can be referred to growth rather than gliding planes. Williams (2) has, however, interpreted polysynthetic twinning as being due to gliding although he describes simple contact twins as growth phenomena.

Growth twinning, following the spinel law, is very common upon the diamond. From the French glass industry the word "macle" meaning stirred (molten hard and soft glasses stirred together) has been taken and applied to diamond twins. When thin twinning lamellae are present, the cutters speak of them as "knots." These knots may be wedge-like portions within the stone which extend completely through the stone, starting at one side and wedging out in the interior, or exist as "islands"

within the stone. Flattened stones are more likely to show twinning, with the twinning plane parallel to the flat sides. Rarely is the contact a true plane, but is more apt to be irregular. Sutton (3) refers to the vacillating character of the composition plane.

Because of the vacillating character of the composition plane there is no tendency for parting to take place between the two halves of the twin. In cleaving a twinned crystal the break proceeds regularly through the first member, but upon meeting the twinning plane will rupture the other member along one, or generally more than one, of the cleavage directions of the second.

The diamond possess an excellent octahedral cleavage and all evidence seems to indicate that breakage in industrial tools takes place along this cleavage. The dodecahedral cleavage is so much more difficult that it occurs only under exceptional circumstances.

The octahedral cleavage is perfect. In comparison with other minerals it is difficult. Our conceptions of the ease or difficulty of cleavage in minerals have been developed by working with large specimens. On the basis of comparable size of crystals, the cleavage in diamond is difficult. In cleaving the diamond it is first necessary to prepare a specially shaped groove to serve as a starting point and the process of cleaving consists of driving a metal wedge into this groove exactly parallel to the plane of cleavage.

In the opinion of some diamond cutters octahedral crystals cleave more readily than dodecahedral ones. They state that the more readily a diamond cleaves the more perfect will be the resulting surface. If we accept Buerger's concept of *lineage structure*, we should expect this, though the development of lineages within the diamond is less pronounced than in other crystals. Variations in crystal habit indicate differences in conditions under which crystallization takes place, and it might be concluded that variations in cleavability will be shown in diamonds from different sources. This affords an explanation of the preference which exists in the industrial diamond industry for Brazilian stones which more commonly show the dodecahedral habit than those from other localities. The evidence is incomplete and in any case such variations are not as important in shaping diamond tools as the proper crystallographic orientation of the stone so that rupture will be least apt to take place.

A proper design for a diamond tool should not only give the dimensional specifications, but should also give the orientation of the crystallographic directions of the diamond with respect to the cutting surface of the tool. This relationship between the crystallographic directions and the working surfaces of a tool has been discussed in a previous paper (4).

A basic consideration in cutting a gem diamond is obtaining the maximum weight in the finished stone. Most diamond crystals are distorted and the orientation of the cut stone is determined by taking into consideration the shape of the rough crystal. The strong tendency to carry this same policy over into the cutting of diamond tools and the reluctance to sacrifice weight for proper orientation accounts for some of the poorest diamond tools. The failure of the tools is then blamed upon the diamond rather than upon improper orientation. If the cutter has available a large inventory of rough stones from which to select a crystal for a specified tool, he can combine proper orientation with a minimum loss of weight.

The force applied at the cutting edge of a tool is only one of the factors that can cause failure. Strain will develop from differential temperatures which give rise to unequal expansion within the crystal, while the tool is in use. The high thermal conductivity and the low coefficient of thermal expansion of the diamond tend to minimize this factor. The following table gives interesting data at ordinary temperatures. No data are available for the temperature ranges at which cutting tools operate.

	<i>Thermal Conductivity</i>	<i>Thermal Expansion (linear)</i> per °C $\times 10^{-4}$
Diamond	0.35	0.009
Steel	0.14	0.110
Silver	1.00	0.188
Glass	0.002	0.090

Experimental evidence indicates that the diamond is but slightly affected by sudden or extreme temperature changes. Single crystals may be heated repeatedly to the highest temperature of the blast lamp and dropped directly into water. Crystals with incipient cracks may, in general, be subjected to the same treatment without breaking. Diamonds have been mixed with thermite which was then ignited. The diamond becomes imbedded in the metallic iron and seems none the worse for the treatment.

There is evidence that indicates that the wear which is shown by some diamond tools is the result of inversion to graphite. Diamond is the unstable modification of carbon at all temperatures above normal, under moderate pressures. At 900°–1000° C. the rate of inversion to graphite becomes perceptible. Under high pressure the diamond is the stable form. The greater the speed of cutting, and consequent higher pressure, the better a diamond tool holds its cutting edge.

In cutting material with a low thermal conductivity which is not ductile, as for example bonded silicates, the diamond may wear and develop a polished "flat" on the cutting edge of the tool. In such an operation

the heat becomes excessive and the pressure on the cutting edge is not continuously uniform but oscillating. It is suggested that this wear may be due to the inversion of the diamond to graphite.

Although there has been a great increase in the use of shaped diamond tools in the past ten years there are still many industrial processes to which the use of diamonds might be efficiently and profitably adapted. The development of these new uses has been greatly retarded by a lack of knowledge of the physical properties of this very interesting mineral.

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(7) BONDED DIAMOND WHEELS

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INTRODUCTION

It is the purpose of this paper to describe a new and economically important development in the use of diamonds, viz., as the cutting constituent of bonded bodies employed in the finishing of tools composed of cemented tungsten and tantalum carbides. These hard materials known by such trade names as Carboloy, Widia, Firthite, and so forth, consist of the carbides in fine granular form bonded with a metal, such as cobalt. The mixtures are molded into shapes at high pressures and sintered in metallurgical furnaces. The furnaces must be carefully controlled with respect to the time-temperature cycle and the atmosphere obtaining in the furnace.

Cutting tools made of cemented carbides for shaping metals have proven so much superior to the tools currently in use that the demand for them in industry has grown to a phenomenal extent. It is the forming, shaping and re-sharpening of cemented carbide tools that made the development of bonded diamond wheels necessary.

It is true that wheels made with silicon carbide grain have been functioning, and are continuing to function, in certain types of application in this field. Despite their lower initial cost as compared with diamond wheels they possess certain disabilities which limit their use. Primarily, the disability of silicon carbide wheels arises from the fact that unless they are extremely free and sharp cutting they tend to produce cracking or checking of the cemented carbide being ground. To avoid this condi-

tion it is necessary to use wheels which wear rapidly and this in turn makes it difficult to maintain accurate dimensions of the carbide tool under "constant feed" conditions of grinding.

The growth in the manufacture of diamond wheels is shown by the following tabulation of relative figures. In this tabulation the production for the year 1936 is taken to be 1.

1936	1	1938	2	1940	5
1937	2	1939	3	1941	19

Manufacture of Diamond Wheels

Briefly the manufacture of diamond wheels proceeds as follows:

The diamond, which is crushing bort and mainly of Belgian Congo source, is purchased in the form of particles varying from approximately 1 to 5 carats each. The material is first fractured through a small jaw crusher, then further reduced in particle size in a steel ball mill using steel balls. The latter operation also serves to produce the desired shape of particle, viz., essentially wedge type with sharp edges and corners.

Sizing is done in a closed sieving system shielded from dust loss. This operation is not continuous since it is carried out on charges of definite weight. The grain sizes produced and used in diamond wheels vary from relatively coarse to quite fine particles, each grit number of which is accurately controlled as to uniformity.

The bonds used for diamond wheels are of two distinctly different types, viz., resinoid and powdered metal.

It must be stated that the wheels consist of centers, or preforms, made of metal or a resinoid molding composition and containing no diamond. The "diamond containing" material is present in the form of thin zones varying in thickness from $\frac{1}{8}$ to $\frac{1}{4}$ " for metal bonded and $\frac{1}{8}$ to $\frac{1}{2}$ " for resinoid. This zone is positioned either at the face (periphery) of the preform or at the side of the preform. The shape of the wheel and the use to which it is to be put governs the position of the bonded diamond zone with respect to the preform.

For each wheel the necessary weighed amount of diamond and bond is carefully mixed together and positioned in a heavy steel mold around the preform. The mold is then pressed to the desired pressure and the wheel removed by stripping off the mold. The wheel is then baked under controlled conditions to harden the resinoid bond properly, or to sinter and completely coalesce the metal bond.

Many sizes and shapes of wheels are made most of which fall into three classifications, viz., straight wheels, cut-off wheels and cup wheels.

Straight wheels are made up to 20" in diameter.

Cut-off wheels are made up to 8" in diameter.

Cup wheels are made up to 14" in diameter.

Of perhaps singular interest to the mineralogist is the fact that the diamond used in all these products is substantially Belgian Congo bort, notwithstanding the fact that industrial diamond experts have declared it to be soft, weak and very inferior to mined South African bort and to Brazilian bort. Of course, their appraisal was probably justified inasmuch as they were considering bort in the relatively coarse lump form for such purposes as the trueing of grinding wheels, as wire drawing dies and for rock drilling heads. However, it was also claimed by some that the fine flours of Belgian Congo bort were useless in lapping and shaping industrial diamonds as well.

Our study of borts from the various sources led to the conclusion that the weakness of Belgian Congo variety was due to cracks, flaws, and other structural conditions which should be practically eliminated when the pieces as bought were crushed down to the desired relatively fine sizes. On this basis and to avoid paying premium prices for the other varieties, we standardized on bort consisting substantially of the Belgian Congo variety for wheel use.

Subsequently, carefully conducted laboratory tests on grinding cemented carbide with resinoid bonded wheels and with metal bonded wheels containing diamond grain from each of the sources verified and justified our conclusion. Recently we have been informed by two of the most important companies engaged in preparing diamond for industrial uses that they can and are successfully using Belgian Congo powders interchangeably with those of the other sources for shaping industrial diamonds.

Uses of Diamond Wheels

As stated previously the chief use for bonded diamond wheels is in grinding cemented carbide tools. In offhand grinding, using cup wheels, the metal bonded type is recommended for sharpening single point tools, for reconditioning excessively dulled or chipped single point tools, for grinding new "milled and brazed" tools and for grinding chip breakers. Cutting-off wheels are employed for cutting sintered carbide blanks to desired lengths, cutting rough semi-sintered blanks to desired shapes and sizes, and for salvaging chipped tools by cutting off the damaged portion of the carbide tip.

The metal-bonded type gives extremely low rate of wear. It is recommended for offhand grinding of tools where a liberal amount of pressure is used, where the carbide tips present sharp and narrow contacts which might prove destructive to the resinoid bonded type. Because of its harder and more heat resistant bond, the metal bonded wheel resists grooving or rounding of the corners to an exceptional degree. For the

same diamond grit size a smoother finish and generally a keener cutting edge is produced with the metal bonded wheel than with a resinoid bonded wheel.

Diamond resinoid wheels are particularly suited for use in plants where carbide tipped tools are ground in large quantities, or on a production basis because its extremely fast cutting action provides the necessary rapid stock removal. They are also particularly suited to fixed feed, precision grinding operations such as cylindrical, surfacing, internal and cutter grinding.

While the first cost of the diamond wheel is necessarily high, appreciable savings in time and ultimate grinding costs result because it is very fast cutting and has an extremely low rate of wear as compared with silicon carbide abrasive wheels.

Additional savings in grinding time are possible with diamond wheels on multibladed tools such as milling cutters, broaches, and inserted tooth saws because of their ability to hold their size, i.e., progressive feeds can be applied to all inserts without leaving inaccuracies due to wheel wear. On tools of this class using silicon carbide wheels, the wheel wear is enough so that each blade or tooth after grinding must be checked separately for size.

Finally, because of the freer and cooler cutting action of diamond wheels the risk of checking or cracking the carbide tip is eliminated and this permits the production and commercial finishing of new, harder, and more sensitive grades of cemented carbides.

As may be expected from the development of such a novel product there has been much interest in possible applications to grinding of other materials and notable progress has been made. For instance, metal bonded diamond wheels are being used commercially for forming the special porcelain insulators of spark plugs.

Both metal and resinoid diamond wheels are being employed for slicing quartz plates used in piezo electric radio wave length controls. It is of interest to record that with a precision surface grinder using fixed feed, quartz plates 0.015" thick are being cut from one inch square pieces maintaining parallelism between faces within less than 0.001". The time per cut is less than 1 minute.

Metal bonded diamond laps of definite curvatures are being used commercially for rough grinding of ophthalmic and instrument lenses. Lens edging is also being done with metal bonded wheels.

Also, consideration must be given to the use of diamond bonded wheels in the field of mineralogy and geology. At the meeting of petrographers engaged on industrial problems which was held at the National Bureau of Standards in May 1940, there was some discussion of the application of

these wheels for cutting off specimens of hard minerals, rocks, and manufactured products as a preliminary step in thin sectioning and in the preparation of surfaces for mineralographic studies. At that time serious limitations were indicated and to a large extent these limitations exist today.

Briefly, the situation may be summarized as follows: in general, the constant pressure machines used by lapidaries and by mineralogical and geological laboratories for slicing work are not in very good condition from the standpoint of the precision required with diamond cut-off wheels. When mounted on such machines the wheels do not run true, they tend to wobble and are subjected to side grinding. Since they are relatively weak against cross bending stresses, breakage frequently occurs.

Precision grinding machines, on the other hand, are almost invariably of the fixed feed type and are of rugged construction. If a diamond cut-off wheel be mounted on such a machine, e.g. a tool and cutter or a surfacing machine, and if it be applied to the specimen using fixed feed with an increment of feed small enough to eliminate an excessive pressure, it is possible to use such a wheel with safety, precision, and with a good cutting rate on hard minerals. In our laboratories specimens of fused alumina abrasive, alumina boules for watch jewels, and boron carbide are regularly being cut off into thin plates with ease.

(8) EVALUATION CRITERIA

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The problem of the proper selection of a diamond for a specific purpose is indeed an important one for there is a large spread between the least and most valuable stones. An adequate evaluation of an industrial diamond must rest on an examination of its physical characteristics, for these determine its effective life. The most probable factors of importance are:

- | | |
|-------------|---|
| 1. Hardness | 6. Inclusions |
| 2. Cleavage | 7. Thermal properties |
| 3. Twinning | 8. Color |
| 4. Flaws | 9. Inversion to graphite |
| 5. Habit | 10. Aggregation of crystals other than twinning |

These are not given here necessarily in the order of their importance because the order of importance may vary depending on the particular use.

Hardness is a crystal property. Different directions in a crystal may vary in hardness, but all crystals of the same substance should have the

same hardness, provided there is no change in the chemical composition and there is no aggregation effect which conceals the true hardness. When certain diamonds are called *soft*, the term is erroneously used to describe lack of *strength*, or lack of *cohesiveness* of a crystal aggregate. According to Klein diamond dust made from inferior Congo crushing bort is just as effective as any other diamond dust. This evidence is substantiated by others in the diamond industry, and it lends strong support to the idea that diamond from whatever locality is about the same in hardness. The evidence also points to the conclusion that whatever strength or toughness properties are peculiar to certain diamonds are due not to inherent properties of the crystal, but to some other factor such as a lineage structure in the sense of Buerger's usage, or a larger scale aggregation. This will be dealt with in more detail later.

Cleavage is perhaps the best understood of all the physical characteristics of a diamond. Slawson has explained how to orient a crystal so that the cleavages will be least likely to develop. A visible cleavage plane within a stone is an obvious defect which diminishes the value of that stone for most purposes. But the failure and wear of all industrial diamonds probably comes about by successive cleavages of small particles and we must consider the effect on cleavage of other characteristics of the diamond.

The twin plane corresponds with the cleavage plane, and it may be a parting plane and, as such, a possible source of weakness. According to Slawson twinning is probably not caused by gliding.

Flaws are usually the loci of weaknesses in a stone. They may be irregular feather-like separations or negative crystal cavities, or incipient cleavages only partially developed. Small negative crystal cavities are not necessarily weakness areas of the stone. Since most industrial diamonds are flawed to some extent, one must examine the stones for the characteristics of the flaw, or its coincidence with cleavage directions, or the amount of strain caused by the flaw.

Inclusions are without doubt a locus of strain in a diamond. Few crystals containing inclusions fail to show strain phenomena around the inclusion when examined in polarized light. While it is true that a diamond may be mounted in a tool with the inclusion away from the working part of the diamond, yet the stone, if it has to be reset, will not perform so well when the inclusion is near the working part of the stone. When the strained part of an inclusion is bared, the stone is more likely to break because of the strain. Flaws and inclusions cannot be tolerated in dies, if they are close to the hole.

The color of a diamond crystal is said to have some effect on its suitability as an industrial tool. Many dark gray to black stones are excellent

stones, but a defect might easily be masked by the opacity. Some of the dark colored diamonds are the result of a great many inclusions of graphite, or other material, and these too might be disadvantageous. But it is difficult to see how evenly distributed color, in itself, could lessen the toughness of a stone, and I doubt whether such color could be considered a disadvantage.

Many diamonds, on close inspection, are seen to be made up of subparallel aggregates of crystals; that is, the external planes, or cleavages, when examined, show deviations from a single plane. These deviations are sometimes a matter of less than a degree on such crystals as the Jaggerfontain or Brazil diamonds, or many degrees as in some of the so-called knotted stones. In the Brazil ballas the deviations are continuous and radial, producing the familiar rounded aggregate. Many Belgian Congo diamonds show a large deviation of many small units so that a granular effect is produced. There is some reason to believe that not only do we have these easily visible deviations from perfect development of the diamond crystal, but we also have to deal with microscopic failure of alignment, in the manner proposed by Buerger for other crystalline substances. The diamond is not peculiar in this respect—I believe most crystals larger than a few millimeters show more or less of the effect of subparallel growth.

This characteristic has a large influence on the strength of a stone and on its ability to withstand cleavage. Slawson states that the more readily a diamond cleaves, the more perfect is its cleavage surface. While such stones as the Brazil ballas and knotted stones cannot be used as shaped tools, they nevertheless are used as wheel dressing and truing tools and are an important part of the total of diamonds used in industry.

For use as unshaped stones, we conclude that the so-called ballas is the best because of its heterogeneous orientation, which prevents any thoroughgoing cleavage from developing. For a similar reason, knotted stones or those showing obvious aggregation of a few individual crystals are also preferred. But this is not a universal rule, for certain diamond crystals, such as some Belgian Congos, show marked deviations from parallelism, but the units are small and granular and pull away from each other.

We have, thus far, enumerated certain characteristics which are advantageous or otherwise. Our criteria of selection must rest largely on the examination of stones in view of these characteristics, and in view of the uses to which the stones are put. In choosing a diamond for a shaped tool, an inclusion in one corner, which will be buried in the tool, is probably not serious and does not detract materially from the value of the stone. However, if the stone is to be reset, the inclusion may be detrimental. For

diamond dies we must have freedom from flaws in the vicinity of the hole. For drills, a diamond must be tough and take heavy overall usage, so that the ballas or knotted stone is called for. A bearing must resist pressure and a stone without serious flaws and a single crystal must be used. Crushing bort can be the cheapest kind of available material without seriously detracting from its usefulness. For the dressing and trueing of grinding wheels a stone like the ballas is to be sought, or one having increased strength through subparallel aggregation.

It is, of course, impossible to get flawless and inclusion-free diamonds of just the right shape and size. These go to the higher priced gem uses. But we can grade the stones and choose the best available for the job, with these criteria in mind.

How is this grading accomplished? Many of you in this audience have handled diamonds so long that you have an intuitive knowledge of the good and bad stones, and their grading is a simple and easy matter. I have on a number of occasions consulted with members of a large local industrial diamond concern in an effort to learn what constitutes a good industrial diamond. The principal reason given by experts for choosing a good stone is that it is good because other similar stones have so proved. For some of us who are inexperienced (and it apparently takes a great deal of experience to pick stones on sight) there may be objective methods of approach.

Examination of flaws can be made with a polarizing microscope. The extent of the strain and the incipient cleavages can be seen under low magnifications. Inclusions can likewise be quickly examined in this way.

The determination of the degree of subparallelism can be most quickly accomplished by the use of a simple reflecting goniometer. A parallel light beam reflected from a cleavage surface or a crystal face will show the extent of the deviation. Usually, however, a qualitative estimate of the subparallelism can be obtained by observation under a binocular microscope. More elaborate techniques are available, such as x-ray Laue diffraction patterns, but these are too time-consuming for general use, although they may be profitable when larger stones are to be examined.

Stones of more brilliance than usual are generally considered tougher. This brilliance may be the result of subparallelism on a microscopic scale, but this needs a careful investigation for verification.

Many of the points discussed may seem obvious and rather academic to the expert in these matters, but it must be remembered that some of those who are now asked to pass on the qualities of stones cannot fall back on long experience as a guide, and, as time goes on, others also will be asked to help in the selection of the ever-increasing quantities of diamond used in industry.

MEMORIAL OF OLAF ANDERSEN*

ROBERT B. SOSMAN, *Research Laboratory, United States Steel Corporation,
Kearny, New Jersey.*

I knew Andersen for nearly thirty years, yet never felt as completely acquainted with him as with several other persons whom I have known for a much shorter time. He was a man of reserve; not aloof, but self-contained and self-reliant in the ways that we are accustomed to expect of the Scandinavian peoples. Yet after every discussion of scientific subjects or conversation on casual affairs, I felt better acquainted than before, and I believe that such would be the testimony of all of his associates.

Olaf Andersen was born at Honeföss, Norway, on the 12th of March, 1884, and died at his home at Millington, New Jersey, on the 18th of July, 1941, in his 58th year. He received his early education in Norway and took his Bachelor's degree at the University in Kristiania (now Oslo) in 1903, at the relatively early age of 19. His subsequent professional career was spent exactly one half in the United States and one half in his native Norway, though not continuously in either country.

He early took up work in the geology and petrology of the pre-Cambrian rocks of southern Norway, in association with W. C. Brögger, and was lecturer at the University in Kristiania. In 1911, eight years after completing his undergraduate training, he received the equivalent of our doctorate in science from the University. What led him in this same year to come to Columbia University in New York City for work in petrology and chemistry I never learned; possibly it was through acquaintance with the American geologists who visited Sweden and Norway on the occasion of the International Geological Congress in 1910. His scholarly ability was quickly recognized in this country and in 1912 he joined the staff of the Geophysical Laboratory of the Carnegie Institution of Washington, to work in collaboration with N. L. Bowen on the alkaline earth silicate systems.

During the armistice in the World War six years later the Norwegian government, in common with many other governments, including our own, failed to realize that the trial of national strength was still unfinished, and assumed that an era of peace and uninterrupted prosperity was beginning. Ambitious plans were made for silicate research in Kristiania, similar to that done in Washington, and Andersen was called back to his native country to head this work under the Norwegian Geological Survey. The next ten years proved, on the whole, disappointing,

* First read at a meeting of the New York Mineralogical Club, Oct. 15, 1941.



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although Andersen accomplished some excellent work during this period on the Norwegian feldspars and pegmatites. The German financial collapse affected neighboring countries, government financing in the face of deficits and uncertain exchange values became more and more difficult, and the opportunity in Kristiania shrank. Under these conditions an opening for an experienced petrologist in the newly organized Research Laboratory of the United States Steel Corporation at Kearny, New Jersey, together with an opportunity for teaching at Stevens Institute of Technology in Hoboken, looked like a better choice, and Andersen returned in 1928 to the land where his best-known work had been done and of which three of his four children were citizens by birth. Here he remained for the final thirteen years of his life.

Andersen was married to Borghild Olsen on the 6th of March, 1913, in New York City. Their children, all now resident in this country, are Ragna, Erling, Erik, and Thor.

Andersen's strongest instinct in science was his feeling for workmanship, for doing thoroughly and exhaustively whatever he undertook. For example, his paper on aventurine feldspar remains the last word on the subject, and in our Corporation Laboratory his report on open-hearth furnace bottoms of magnesite is referred back to as a standard. Equally thorough was his preparation of a subject for a scientific address or for instruction, and one of his deepest interests in recent years was his class in geology and petrography at Stevens. He was also gratified to be invited to give a series of lectures at Princeton in 1934, and to take over for a time the classes that had been interrupted by the death of Professor R. J. Colony at Columbia in 1936.

Andersen was not active in many scientific and technical organizations but his ability was quickly recognized in those in which he did take a part. He was president and councilor of the Geological Society of Norway (Norsk Geologisk Foreningen), and received its Reusch Medal in 1931. He was also a member of the Geological Society of Stockholm, and became a Fellow of the Mineralogical Society of America in 1931. He was elected president of the New York Mineralogical Club for the year 1939, and it was a matter of deep regret to us all that he was prevented by his final illness from taking part in the meetings of this Club during the latter part of his term as its president.

The appended bibliography covers his published work but does not include a large number of confidential reports made to the Research Laboratory and the technical committees of the Steel Corporation on such subjects as silica brick, magnesite, olivine, chrome ore, and calcium aluminate cement.

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MEMORIAL OF GEORGE MARTIN HALL

HAROLD CLYDE AMICK, *University of Tennessee, Knoxville, Tennessee.*

George Martin Hall died at his home in Baltimore, Maryland, on the 28th of April, 1941, at the age of forty-nine, after a period of failing health that lasted more than four years. He was born in Baltimore, September 13, 1891, the son of George Arlow Hall and Alice Josephine (Higgins) Hall. His early education ended with his graduation from the Baltimore City College in 1909. In the fall of 1911 he entered The Johns Hopkins University and received the degree of Bachelor of Arts in 1915. The following autumn he began graduate work in the Department of Geology of the same University. He continued his studies of geology until he entered the Signal Corps of the United States Army in March 1918. He was commissioned in August 1918 and served as a Second Lieutenant until November 1920. In December of the same year he returned to Johns Hopkins and again took up his work in geology and received the Ph.D. degree in 1923.

During part of the summer of 1915, he did field work on the Silurian rocks of western Maryland for the Maryland Geological Survey. The summer of 1916 was spent investigating fire clays of Allegany and Garrett Counties, Maryland, for the same organization. The summer of 1917 was spent in Kentucky and Kansas, working for the Roxana Petroleum Corporation. In June 1921 he received an appointment as Assistant Geologist on the United States Geological Survey and was assigned to the Ground Water Division of the Water Resources Branch. He spent the summers from 1921 to 1924 investigating the ground water resources of eastern and central Montana. From 1921 until his death he remained a part time member of the Ground Water Division of the Geological Survey. During the later years of his life most of the time devoted to the Ground Water Division was spent in the office at Washington, D. C. During the summer of 1925, he was engaged in field work in southeastern Pennsylvania, the results of which were presented in Bulletin W2 of the State Topographic and Geologic Survey. In the fall of 1923, he accepted an instructorship in Geology at The Johns Hopkins University, a position he held until the fall of 1926 when he came to The University of Tennessee.

Dr. Hall came to The University of Tennessee as an Associate Professor of Geology, at the invitation of Dr. C. H. Gordon. He held this position until 1929 when he was appointed Professor and Head of the Department of Geology and Geography, a position he held until his death.

Coming to The University of Tennessee in full vigor at the age of thirty-four, Dr. Hall devoted his time and energy to the broad problems of higher education and scientific research. His devotion to science and



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teaching was very real and the result of much thought by a man who had seen the other aspects of the world. His geologic work was straightforward and sincere. Active field work always appealed to him and when not connected with an official survey he was working on a project of his own choosing. When he came to Tennessee he began work on the Paleozoic rocks of the Ridge and Valley Province and the premature termination of his active career left unfinished a program that had promised to contribute much information to the field of Earth Science.

Dr. Hall considered the earth his laboratory, which led him to travel extensively. Some of the high lights of his career were the trips he made with the International Geologic Congress. During the summer of 1926, when the Congress met in Spain, he visited numerous points of geologic interest in northwest Europe and north Africa. Then in 1929 he went with the Congress to the major points of interest throughout South Africa. In 1933 when the Congress met in Washington, D. C., he was one of those who took an active part in entertaining our distinguished visitors. He also took the tours which covered the most attractive parts of the continent of North America. It was his intention to attend the Congress that was held in Russia in 1937 but failing health prevented him from doing so. On these tours he made the friendship of many of the outstanding men in the fields of Earth Science throughout the world, and he always came back with a great store of first-hand information which he gladly imparted to his students and his many friends.

As a reward for the high quality of his scientific work, he was elected to fellowship or membership in the following national professional societies: Geological Society of America, Mineralogical Society of America, American Institute of Mining Engineers, Society of Economic Geologists, and American Association of Petroleum Geologists. He was also a member of the Cosmos Club, Gamma Alpha, and the Society of Sigma Xi, and had been honored by being selected for listing in *Who's Who in America*.

Soon after coming to The University of Tennessee, he joined the Tennessee Academy of Science and served as its president in 1934. He also served as president of the Knoxville Technical Society in 1932. He was a charter member of the Knoxville Science Club and had the honor of being its first president in 1934. He demonstrated his interest in local civic affairs by joining the Knoxville Rotary Club and he found the association with its members very gratifying.

Until his health failed, Dr. Hall enjoyed life and never took himself too seriously. Disappointments were in his experiences, but he retained a genial personality which radiated cheer and good will toward all with whom he came in contact. Always an interesting lecturer and public speaker, he was much in demand. His associates admired and respected the sincere and fearless manner with which he entered into a discussion.

An alert mind, a broad and accurate knowledge of many subjects made his conversation crisp and interesting. His friends knew him as a modest and sincere idealist, who regarded truthfulness and honesty as unexcelled virtues. He never married, and in the absence of family cares, devoted his time and thoughts to the field of Earth Science, for which he will long be remembered.

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MEMORIAL OF JAMES F. MORTON

O. IVAN LEE, *Jersey City, New Jersey.*

James F. Morton, Curator of the Paterson Museum since 1925, died at St. Joseph's Hospital in that city early on the morning of October 7, 1941, from injuries received the previous evening in near-by Totowa Borough, where he was struck by an automobile. His tragic death was a shock to his own community and to the metropolitan area where he had many friends and acquaintances due to his activity in civic, social, literary and scientific circles.

He was a direct descendant of an old American family which has lived here since the landing of the Pilgrims in the year 1620. Mr. Morton's grandfather, Rev. Samuel Francis Smith (1808-1895) was the author of the words of the song "America." Born in Littleton, Massachusetts, on October 18, 1870, Mr. Morton was the son of the late James Ferdinand Morton and Caroline Edwards (Smith) Morton. His father was at one time the principal of Phillips Academy in Exeter, New Hampshire.

He received his Bachelor of Arts and Master of Arts degrees from Harvard from which University he was graduated with "cum laude" in 1892. He was an outstanding student while in college. He was a member of Phi Beta Kappa Alumni of New York and was largely responsible for the establishment of inter-collegiate debate. Later he became a member of the New York and Massachusetts bars.

Mr. Morton also attended and graduated from the Curry School of Expression. For several years he traveled extensively and gained considerable prominence as a lecturer speaking on various social and literary topics. During his youth he also spent considerable time in France which enabled him to use the French language fluently.

The exceptionally wide scope of his interests is evidenced by his being a member of the National Amateur Press Association, of which he was a former president; former vice-president of the Esperanto Association of North America (a group which seeks to establish a universal language); a former president of the Thomas Paine National History Association; and a leader in the American Association of Museums, American Forestry Association, and the Science League of America.

Mr. Morton was an ardent advocate of the single tax plan, and the author of the two books on the subject, "The Philosophy of the Single Tax" and "Single Tax Review." In another book entitled "The Curse of Race Prejudice" he championed Negro rights. He was a member of many societies and clubs including: The Harvard Club, Blue Pencil Club, Institute of American Genealogy, Genealogical Society of New Jersey, League of Nations Non-Partisan Association, Paterson Manu-



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script Club, Rocks and Minerals Association, and others. His love of natural science and history developed a deep appreciation for minerals. For many years he was a Fellow of The Mineralogical Society of America, and a highly esteemed member of The New York Mineralogical Club. Although nearly 71 years of age, he was remarkably active and energetic and very fond of walking and visiting mineral localities far and near. His accounts of the results of these excursions were always characterized by great factual clarity and by the refreshing enthusiasm of a born collector.

As Curator of the collections under his care, he had expanded them until the Paterson Museum had attained an enviable national reputation. When the International Geological Congress met in Washington in 1933, its members signified their desire to visit three museums possessing mineralogical specimens of special interest to them—the Smithsonian Institution, the American Museum of Natural History, and the Paterson Museum. Three hundred delegates made the pilgrimage and were amazed at the richness and scope of the mineralogical exhibits. A group of specimens from Franklin especially impressed them, while the Paterson minerals, of which Mr. Morton had listed more than 57 species, were deemed of surpassing interest.

In years to come, many visiting mineralogists will study the Museum collection with pleasure and profit, and marvel at and admire the splendid specimens there assembled and displayed, but the genial charm and the quiet cultured discourse of its late custodian will be sadly missed but long remembered by those who were privileged to know him best.

Mr. Morton is survived by his wife, the former Pearl K. Merritt, as well as by two brothers, Frank, of South Sudbury, Massachusetts, Nelson, of Melrose Highland, Massachusetsts, and one sister, Mrs. Mary Ziegler of Gates Mills, Ohio.

MEMORIAL OF ALFRED WANDKE

L. C. GRATON, *Harvard University, Cambridge, Massachusetts.*

Alfred Wandke was born at Lisbon Falls, Maine, on May 13, 1887, graduated from Lewiston High School in 1906, from Bowdoin College in 1910, and from the Graduate School at Harvard in 1917. After many years spent in Mexico as mining geologist and mine operator, he was killed near Guanajuato, Mexico, February 14, 1941.

An appreciative record of Wandke's life with appropriate elaboration of the foregoing brief chronology having been prepared for the Geological Society of America by his good friend, Dr. M. N. Short, the present account may dwell especially on those characteristics which were so notably developed in this enthusiastic scientist.

Wandke inherited from his German-born parents a constitution tough as leather, a serious driving power that never tired, a sunniness that never dimmed, and a mind that never ceased inquiring. His high-pressure devotion to work and study while growing to maturity was balanced by a spontaneous joy in athletics and an unquenchable liking for human beings. Reaching his goal of a thorough training by the route of self-support, he came relatively late to the professional study of geology; but when he received his doctorate at the age of 30 his power was proportionate to his years.

The first professional job of Wandke's was at the important Pilares Mine at Nacozari, Mexico, where he quickly demonstrated his ability to handle both geology and men. This connection was interrupted by his entry into the War, where he carried on as vigorously and loyally as any tenth-generation American. Next he was included in the group that made an intensive four-year study of the Calumet and Hecla, one of the world's foremost copper producing companies that had never previously felt the need for systematic geology. Wandke was especially charged with the petrographical work, but participated also in the investigations in the several mines. It was here that first came into evidence his remarkable "photographic" memory, which enabled him to carry in mind a wealth of details regarding the underground, and which he later put to such excellent use in the finding of previously unsuspected ore shoots in centuries-old mines of Mexico.

Wandke was sent to Mexico in 1923 by the New York management of a famous but supposedly nearly-exhausted mine in the Guanajuato district, nominally as geologist but actually to perform a mission requiring the utmost in judgment, tact, decisiveness and, as it proved, physical courage. His discharge of this task was so eminently satisfactory that he was shortly made manager of the property. For several years previ-



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ously the operations had been conducted at a loss, and he had no capital to spend. But he managed to revamp equipment, achieve cleaner mining, raise recoveries, improve safety, and counteract the growing power of the mine unions by imbuing his workmen with the same objective as his own—viz., to restore prosperity to the grand old mine. His enthusiasm and unsparing expenditure of his own energy became contagious; the men accepted lower wages and worked harder, they quashed strikes before these got started, and when there was no longer money for pay rolls they turned with such effectiveness to leasing that royalties saved the day. In the 16 trying years as manager of this property Wandke had the satisfaction of seeing it emerge from the red to a resumption of profits—practically all of it won from ore unknown when he took control and found through his happy combination of scientific knowledge, keen observation, retentive memory and unrelenting application.

A little over a year before he was killed, he turned his entire attention to the operation of properties in which he personally was concerned, one in Zacatecas, the other on the outskirts of Guanajuato. This inaugurated a new cycle of uphill fights against the familiar enemies: timidly-hiding ore bodies, high costs, labor unrest and fickle metal prices. Pushing himself as ever before, he again imparted to those about him a sense of loyalty and cooperation which, coupled with his uncanny ability to find ore, promised to turn these undertakings into substantial successes. It was while driving at his usual pressing pace along the rough mountain road leading to one of these mines that a wheel gave way on a curve and plunged him to his death.

Wandke's preoccupation with men and materials and money never for an instant reduced his profound interest in geology. His boundless faith in the properties he handled rested on the conviction that sufficiently intelligent geological effort unremittingly applied would succeed in finding more ore where so much had already been found. He strove as conscientiously to keep abreast of current theory and method in mining geology as to maintain modern supplies in his warehouses and efficient equipment in his mines; he held membership in the American Mineralogical Society, the Geological Society of America, the Society of Economic Geologists and the American Institute of Mining and Metallurgical Engineers.

He travelled widely over the extensive Mexican metallogenetic province and was deeply impressed by the beauty and importance of the geological principles there revealed. It was his firm conviction that on certain grand problems of structure and of ore genesis no other area could shed so much light, and his only complaint about his heavy practical duties was that they prevented his immediate plunging into these absorbing scientific puzzles. He had long devoted time to a gradually

improving program of geological research in the Central Plateau which he hoped to support. Indeed, the mainspring of his almost feverish activity was the vision of completing early the provisions for his family so that resources thereafter might be devoted to research stipends for a succession of able young geologists to cooperate with him in this appealing investigation.

His geological writings are not numerous; but they reveal a penetrating insight and understanding of high order. Those of the later years in particular, produced when his major duties demanded the utmost in other directions, are a remarkable tribute to his deep scientific instinct and to his command over self. Perhaps the most significant of his contributions are: the recognition by careful microscopical work of alteration processes associated with the ores of Sudbury, which showed that the theory of magmatic segregation could not survive in the oversimplified form in which it was then visualized; the clearly recorded testimony of filled veins of low dip at Guanajuato in support of the thesis that the fracture walls were spread by the pressure transmitted by the ore-forming solutions; and the evidence deduced from cross-cutting veins at Tepezala that the pyrometasomatic processes are intimately related to the hypothermal.

Wandke's capacity for friendship was as deep and constant as his power to work. His letters to old friends were exuberant, informing and genuine. In his professional domain and in his home he revealed generosity, good cheer and the joy of learning and doing. He fought the good fight, and he died in harness, as would have been his wish.

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PROCEEDINGS OF THE TWENTY-SECOND ANNUAL MEETING OF THE MINERALOGICAL SOCIETY OF AMERICA AT BOSTON, MASSACHUSETTS

PAUL F. KERR, *Secretary*.

The twenty-second annual meeting of the society was called to order Monday, December 29, at 2 P.M. in the Ballroom Foyer of the Hotel Statler in Boston, Massachusetts, president Frederick E. Wright presiding. The customary business of the society was conducted, including reports of the officers of the society and committees, summarized as follows:

MINUTES OF THE TWENTY-FIRST ANNUAL MEETING, 1940.

REPORT OF THE SECRETARY.

REPORT OF THE EDITOR.

REPORT OF THE TREASURER.

REPORT OF THE AUDITING COMMITTEE.

MEMORIALS TO OLAF ANDERSEN, GEORGE M. HALL, JAMES F. MORTON, AND ALFRED WANDKE, PRESENTED BY DEAN EDWARD H. KRAUS.

The business meeting was immediately followed by the scientific session. The report of the election of officers and fellows for 1942, and the reports of the officers are given in the following pages.

ELECTION OF OFFICERS AND FELLOWS FOR 1942

The secretary announced that 298 ballots had been cast for the officers of the Society as nominated by the Council.

The officers for 1942 are:

President: Arthur F. Buddington, Princeton University, Princeton, New Jersey.

Vice-President: M. J. Buerger, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Secretary: Paul F. Kerr, Columbia University, New York, New York.

Treasurer: Earl Ingerson, Geophysical Laboratory, Washington, D. C.

Editor: Walter F. Hunt, University of Michigan, Ann Arbor, Michigan.

Councilor, 1942-45: Adolf Pabst, University of California, Berkeley, California.

The secretary announced that according to the provisions of the constitution the following have been elected to fellowship:

Anderson, George H., Texas Power and Light Company, Dallas, Texas.

Bullard, Fred M., University of Texas, Austin, Texas.

Campbell, Charles D., Washington State College, Pullman, Washington.

Chapman, Randolph W., Johns Hopkins University, Baltimore, Maryland.

Colburn, William B., Cranbrook Institute, Cranbrook, Michigan.

Fraser, Horace J., California Institute of Technology, Pasadena, California.

Fuller, Richard E., University of Washington, Seattle, Washington.

Gianella, Vincett P., University of Nevada, Reno, Nevada.

Goldich, Samuel S., Texas Agricultural and Mechanical College, College Station, Texas.

Gysin, Marcel, Mineralogical Laboratory, University of Geneva, Geneva, Switzerland.

Harcourt, G. Alan, International Nickel Company, Copper Cliff, Ontario, Canada.

Schmitt, Harrison A., Box 572, Silver City, New Mexico.

Stewart, Duncan, Jr., Lehigh University, Bethlehem, Pennsylvania.
 Stow, Marcellus H., Washington and Lee University, Lexington, Virginia.
 Watanabe, Takeo, Hokkaido Imperial University, Sapporo, Japan.

REPORT OF THE SECRETARY, 1941

MEMBERSHIP STATISTICS

	1940	1941
Correspondents	7	6
Fellows	191	193
Members	457	426
Subscribers	334	314
	<hr/>	<hr/>
	989	939
	Gain	Loss
Correspondents	0	1
Fellows	15	13
Members	107	138
Subscribers	59	79
	<hr/>	<hr/>
	181	231

During 1941, the net loss in total membership has been 50, approximately the same as in 1940, and once again a 5% decrease on the basis of the previous year's total. In view of the present state of international conditions, the net decrease is probably unavoidable. The secretary has included in this decrease certain subscribers who have requested suspension for the duration of the war; also the one correspondent, one fellow, and four members in Paris, France, with whom mail service has been discontinued since they are within the occupied zone.

Respectfully submitted,

PAUL F. KERR, *Secretary*

REPORT OF THE EDITOR FOR 1941

To the Council, Fellows and Members of the Mineralogical Society of America:

The past year has been one of increased apprehension for all concerned with the Society's welfare. The year 1941 had not advanced many months before it became apparent that some degree of retrenchment would be necessary as the expenditures of what might be considered a normal volume were exceeding anticipated income. Of course the disturbed foreign situation was mainly the cause for the reduced revenue. This tendency was clearly indicated in the reports of our Secretary and Treasurer a year ago, and the events of the past twelve months certainly have not clarified the situation to any extent.

Following a request received from the Treasurer in the spring to cut publication costs, the Editor found it necessary to reduce the size of the Journal so that monthly costs would not exceed \$400 for an issue of 1350 copies. Previously, over a period of years, the budget permitted an average monthly expenditure of \$500. This new budget calling for a reduction in printing costs of 20% was faithfully adhered to and no monthly issue of the Journal after the March number exceeded the figure indicated. In fact the actual monthly printing cost for the last eight issues (April to Nov. inclusive) was \$370.62.

In a number of instances the Editor has been able to secure from authors or institutions

some financial aid to help defray the cost of cuts when the number of illustrations in any single article seemed to place too heavy a burden upon the Society.

This background seems necessary if one is to render a just verdict on the accomplishments for the year. Volume 26 is smaller by 92 pages than volume 25 (1940). In fact, the present volume is the smallest the Society has issued since 1934.

To those who would charge that the volume of material published is no true criteria of the value of a publication, it will be readily admitted that the terms quantity and quality are not identical, nevertheless in rendering a report and making comparisons from year to year, it is still necessary to employ tangible measurable units and to speak in terms of the number of printed pages.

The necessity for retrenchment has in some instances delayed publication of articles, particularly the longer and more costly ones. This is to be regretted but the conditions imposed made it unavoidable. When all factors are properly evaluated I believe it can be said that the Journal during 1941 has carried on in a satisfactory manner.

Summarizing some of the factual data for the year, we find that vol. 26 contains 736 pages, exclusive of index. Approximately 82.6% of the total space of the Journal is devoted to leading articles which number 61. While a few of these major contributions are fairly long, the *average* length is slightly under 10 printed pages. Table 1 which accompanies this report indicates the distribution of the leading articles in the eight fields covered by the Journal. Slightly more than one-half of the papers printed this year fall in the divisions of descriptive, chemical, and structural mineralogy. If to these main articles we add 23 shorter papers, appearing under the section of Notes and News, we obtain a total of 84 published manuscripts for the calendar year. These contributions were received from 74 contributors associated with 47 different Universities, research bureaus and technical laboratories. *The American Mineralogist* for 1941 carried detailed descriptions of six new minerals: whitlockite, sjögrenite, barbertonite, manasseite, djalmaite, and bradleyite.

As in former years a fairly large number of contributions came to us from widely scattered areas outside of United States proper. Of the 84 published manuscripts, 14 (9 major articles and 5 shorter ones) were received from the following 10 sources: Australia, Brazil, Canada, England, Hawaiian Islands, Japan, New Zealand, South Africa, and Soviet Russia.

Finally, what are the prospects for 1942? With world conditions changing almost daily and keeping in mind especially the momentous events of the past few weeks, it is of course impossible to predict how the many interrelated factors will affect the work of the Journal. Printing costs will not diminish, all indications point to a movement in the other direction. Dislocation of normal research in mineralogical and geological fields, with greater stress placed on immediate problems connected with national defense, will no doubt affect our publication, as well as others, but to what extent cannot be foretold. At the present writing sufficient manuscripts are on hand to take us through the summer issues.

In conclusion, I do not wish to leave with you a picture composed entirely of shadows. There is a brighter side. As you are aware the Geological Society of America, for a period of years, has graciously contributed \$1500 annually to assist our Society in meeting publication costs. Last fall, at the invitation of the Publications Committee of the G.S.A., our Treasurer appeared before that body and discussed with them some of our present problems and needs of the Journal for 1942. After a sympathetic hearing the Council of the G.S.A. recommended for the year 1942 that the annual stipend of the Mineralogical Society be increased to \$2000, with the understanding that a year hence another opportunity will be afforded to again review the situation. This additional income will materially assist in neutralizing, in part, the increasing loss in revenue resulting from a decrease in annual dues and subscriptions.

The accompanying table of contents summarizes in detail the distribution of subject matter in volume 26.

TABLE 1. DISTRIBUTION OF SUBJECT MATTER IN VOLUME 26

<i>Subjects</i>	<i>Articles</i>	<i>Pages</i>	<i>Per Cent of Total</i>
Leading articles*			
Descriptive mineralogy	13		
Chemical mineralogy	10		
Structural crystallography	10		
Geometrical crystallography	6		
Petrography	6		
Optical mineralogy	6		
Memorials	4		
Miscellaneous	6		
	61	608	82.6
Short articles	23	60	17.4
Proceedings of societies	13	50½	
Notes and news	13	1½	
Abstracts of new mineral names	26	11½	
Book reviews	6	4½	
	142	736	100.0
Total entries			
Illustrations	196		
Index, covers, advertisements		88	
Grand total		824	

* (Average length of leading articles, 9.9 printed pages.)

Respectfully submitted,

WALTER F. HUNT, *Editor*.

REPORT OF THE TREASURER FOR 1941

To the Council of the Mineralogical Society of America:

Your Treasurer submits herewith his annual report for the year beginning December 1, 1940 and ending November 30, 1941.

RECEIPTS

Cash on hand December 1, 1940.....	\$1,711.39
Dues and subscriptions.....	2,701.37
Advertisements.....	298.38
Sale of back numbers.....	76.62
Authors' charges on separates.....	469.55
Interest and dividends from endowment.....	2,528.50
Sale of 20-volume index.....	18.00
Geological Society of America grant for 1941.....	1,500.00
Partial payments (1941) on principal of Trenton Mortgage Service Company's preferred stock.....	287.57
Aid from authors in publishing long papers.....	130.00
	<hr/>
	\$9,721.38

DISBURSEMENTS

Printing and distribution of the Journal (12 issues)	\$5,128.43
Printing and distribution of separates	681.01
To the Editor, Secretary, and Treasurer	970.00
Postage	166.92
Printing	118.80
Stationery	78.54
Office equipment	98.45
Clerical help	446.50
Committee expenses	2.32
Safety deposit box	8.88
Exchange on Canadian checks	1.07
Refund of dues	3.00
Check returned	3.00
Roebing Medal, 1940	100.00
Expenses of British Consul from Houston to Austin to receive the Roebing Medal	15.00
	<hr/>
	\$7,821.92
Cash balance November 30, 1941	1,899.46
	<hr/>
	\$9,721.38

The endowment funds of the Society as of November 30, 1941, consist of the following securities:

45 \$1,000 bonds, City and County of Honolulu, Territory of Hawaii, Water Works, 5%, due April 15, 1954	\$45,000.00
4 \$100 bonds, Great Northern Railway Company, Genl. Mtg., 5½%, due January 1, 1952	400.00
37-514/1000 shares, Trenton Mortgage Service Company, Trenton, N. J., preferred stock	2,772.33
5 shares, American Telephone and Telegraph Co., common stock	620.57*
5 shares, Public Service of New Jersey, 8% preferred stock	702.00*
5 shares, United States Steel, 7% preferred stock	502.45*
10 shares, Consolidated Edison, 5% preferred stock	1,066.64*
20 shares, Union Pacific Railroad Co., 4% preferred stock	1,607.75*
	<hr/>
	\$52,671.74

* Purchase price.

Respectfully submitted,
EARL INGERSON, *Treasurer*

REPORT OF THE AUDITING COMMITTEE

To the President of the Mineralogical Society of America:

The Auditing Committee has examined and verified the accounts of the Treasurer of the Mineralogical Society of America, for the fiscal year ending November 30, 1941. The securities listed in the Treasurer's report, with all future coupons on the coupon bonds attached, are in the safety deposit box at the Friendship Branch of the Riggs National Bank of Washington, D. C.

Respectfully submitted,

E. F. OSBORN, *Chairman*

MICHAEL FLEISCHER

HERBERT INSLEY

DANA FUND

Statement of the Special Dana Fund of the Mineralogical Society of America, initiated by Prof. E. S. Dana, and since his death cared for by W. T. Schaller. No disbursement made during the fiscal year 1941.

RECEIPTS

Available balance, November 30, 1940.....	\$877.88	
Interest.....	17.60	
	<hr/>	\$895.48

DISBURSEMENTS

Disbursed.....	\$ 0.00	
Available balance, November 30, 1941.....	895.48	
	<hr/>	\$895.48

Respectfully submitted,

WALDEMAR T. SCHALLER

ANNUAL LUNCHEON

The annual luncheon of the Mineralogical Society of America was held in the Hotel Statler, Boston, Massachusetts, at 12 noon on Monday, December 29, with one hundred and fifteen members and friends of the society present. President Frederick E. Wright presided and served as toastmaster during the informal program. Dr. Clarence S. Ross, of the U. S. Geological Survey, presented the fourth Roebling Medal to Dr. Esper Signius Larsen, Jr., of Harvard University. After the presentation, informal comments were added by Professor Palache, Dr. Schaller, Dr. Kerr, and Dr. Wright.

PRESENTATION OF PAPERS

PRESIDENTIAL ADDRESS

METHODS AND INSTRUMENTS USED IN MINERALOGY

FRED. E. WRIGHT

Experience has shown that progress in any branch of science involving measurement and experiment depends in large degree upon the development of methods and apparatus appropriate to the attack on specific problems as they arise. Mineralogy is no exception to this rule. Its record shows that with the introduction of each important new method or instrument new fields of research have been opened and deeper insight into its problems has been obtained. Mineralogy, on the one hand, describes and classifies the various kinds of minerals that occur in the earth's crust and in meteorites; to that extent is a branch of natural history. On the other hand, in the study of minerals many of the methods of physics and chemistry are employed and these imply measurements with the aid of suitable apparatus; to this extent mineralogy enters the field of exact science. The data obtained by mineralogists by use of physical and chemical methods are subject to the same criteria that apply to research work in exact science. In this paper a brief survey will be made of the more important methods and instruments used in mineralogy with special reference to their range of application, their degree of accuracy, and their usefulness.

THE LEAD-URANIUM-THORIUM RATIOS OF VARIOUS ZONES OF A SINGLE CRYSTAL OF URANINITE FROM SPRUCE PINE, NORTH CAROLINA

CHESTER M. ALTER AND EARL S. MCCOLLEY

It has been shown by investigations in our laboratory that the lead-uranium-thorium ratio may vary in different regions of a single crystal of uraninite. This fact has important bearing on the usefulness of such data for calculating the age of minerals. By a technique of removing successive layers or zones from the surface of crystals and analyzing the removed material, it has been possible to study these variations. Work already published indicates that this variation may be quite substantial as in the case of uraninite from Wilberforce, Ontario.

In order to further study this phenomenon, a selected crystal of uraninite from Spruce Pine, Mitchell County, North Carolina, was treated by the method described by Alter and Yuill. In this case, the crystal was divided into three zones, namely, outside, middle, and core. Each zone was analyzed separately for acid-insoluble material, lead, uranium, and thorium. From these data the lead-uranium-thorium ratio and the age of the mineral can be calculated.

The following table gives a summary of analytical data:

Zone	% acid-insol.	% Pb	% U	% Th	Pb	Approx. Age (million years)
					U+0.36 Th	
Outside	2.06	3.19	67.65	0.03	0.0471	358
Middle	1.78	3.40	69.92	.14	.0486	369
Core	1.52	3.50	69.65	.04	.0503	382

The results show fair agreement with analyses of Spruce Pine uraninite reported by Hillebrand and by Boltwood many years ago. The variation in the thorium content of the middle zone and the core is of the same type as that already noted in the Wilberforce crystals, although the thorium content here is much smaller.

THE SYSTEM $\text{CaO-SiO}_2\text{-P}_2\text{O}_5$

RICHARD L. BARRETT AND WILLIAM J. McCAUGHEY

The system contains in addition to the binary phases previously described in the literature, two ternary phases, nagelschmidtite and silicocarnotite which have been previously

known as constituents of certain slags. The equilibrium diagram presents some features of special interest. The field of cristobalite is very large. There is an extensive region of liquid immiscibility in which two liquids in equilibrium with cristobalite are formed. Very extensive solid solution prevails in the four phases, calcium orthosilicate, nagelschmidtite, silicocarnotite, and tricalcium phosphate, which form a binary system with the first and last named as end members. Calcium orthosilicate may contain up to 10% P_2O_5 in solid solution, and nagelschmidtite, the formula for which may be expressed $Ca_7Si_2P_2O_{16}$, can have a P_2O_5 content varying between 12% and 24%. The solid solution seems to be of the substitution sort with PO_4 groups replacing SiO_4 groups. In both phases refractive indices decrease as P_2O_5 content increases.

NATURE AND ORIGIN OF THE EDWIN CLAY, IONE, CALIFORNIA

THOMAS F. BATES

The Edwin clay occurs near Ione, California, thirty miles southeast of Sacramento. It is a residual clay of commercial importance found in but two places near Ione. On the east it is separated from the Mariposa formation, which forms the Sierra Nevada foothills, by a linear, northwest-southeast trending trough containing the anauxite-bearing sedimentary clays and sands of the Ione formation of Eocene age. West of the Edwin clay and forming the western limit of the trough is a prominent outlying ridge of greenstone of the Mariposa formation. It is separated from the clay by a narrow belt of red laterite.

The Edwin clay is a highly refractory kaolin clay used for the manufacture of fire brick. It varies from white to various shades of pink, blue, or gray; and is crumbly, brittle, or plastic.

Heretofore, it has been regarded as one of the sedimentary clays of the Ione formation. However, recent field work, microscopic study, and evidence secured from firing tests show that the Edwin clay has been derived directly from the laterite. Transitions observed in the field, similar textures, and other evidence suggest that the laterite is intimately connected with the greenstone.

THE STRUCTURE OF METHYLENECYCLOBUTANE AND HEXAMETHYLETHANE


L. H. BAUER AND J. Y. BEACH

We undertook this electron diffraction study with the view of verifying the presence of 90° C-bond angles in methylenecyclobutane, and establishing the relative orientation of the methyl groups in hexamethylethane. Our results may be summarized as follows:

Methylenecyclobutane:—the carbon atoms are coplanar, four of them situated at the corners of a square ($1.56 \pm .03$ Å on side), the fifth on an extension of one of the diagonals ($1.34 \pm .02$ Å from the carbon atom in the ring).

Although some investigators expressed doubt as to the possible synthesis of spiropentane, stating that such attempts generally lead to methylenecyclobutane, it is clear from a comparison of our curves with the data of Rogowski (who claims he obtained electron diffraction photographs of the spiro compound), that he did not have methylenecyclobutane, and that very likely he did have spiropentane. However, due to the incomplete description of his photographs, it is not possible to state definitely that he did not have either vinylcyclopropane or 2-methylcyclobutane (1).

Hexamethylethane:—the radial distribution curve shows two sharp peaks, one at $1.53 - \text{\AA}$ (as expected for C-C), and another at 2.55\AA (somewhat larger than expected

for , suggesting that the central C-C bond distance is somewhat stretched. Due to the possibility of hindered rotation about this bond, we made careful intensity calculations, using (Z-f) and temperature factors, and the approximate formulas developed by

Debye for free rotations and torsional oscillations. Although the curves for free rotation, eclipsed and staggered configurations differ by very little, agreement with observation is slightly better for the staggered model. However, regardless which of these models one uses, assuming that the central C-C bond is somewhat stretched (1.58 ± 0.02 Å) improved the correlation with the observed curve. The other distances are: C-C = $1.54 \pm .02$ Å; carbon valence angles $110^\circ \pm 2^\circ$; C-H = 1.09 Å (assumed).

The approximations made in the above calculations will be enumerated and a more accurate graphical method will be presented for discussion.

EVALUATION CRITERIA

HARRY BERMAN

Significant phases of the papers on diamond will be briefly summarized. The various factors that may lead to the formulation of criteria for the evaluation of industrial diamonds will be discussed. Problems involving further study and research will be suggested.

ANALYSIS AND AGE OF MONAZITE FROM DEER PARK NO. 5 MINE, SPRUCE PINE, NORTH CAROLINA

ALLEN D. BLISS

The above-named sample of monazite collected by Professor Adolph Knopf has been analyzed for uranium, thorium, and lead by Fenner's procedure, giving for thorium 4.81 and 4.86%; lead, 0.131 and 0.134%; and a very small amount of uranium (if any), 0.01%. Calculation of the age by the use of the logarithmic formula gives 600 million years.

DISTRIBUTION OF MINOR CHEMICAL ELEMENTS IN TERTIARY DIKE ROCKS OF THE FRONT RANGE, COLORADO

JOSEPH M. BRAY

Qualitative and quantitative spectrographic analyses determining the minor chemical constituents in a number of Colorado Front Range Tertiary dike rocks and their constituent minerals revealed a number of interesting relationships. The rocks analyzed were mainly monzonites and latites.

Rock analyses (qualitative) showed some regional differences in the number and quantity of minor elements present. Slight variations with rock type also were found. Elements of special significance in the rock analyses are: Co, Cr, V, and La.

Analyses of plagioclase, biotite, groundmass, and magnetic concentrate samples (both qualitative and quantitative) showed systematic differences in the number and quantity of minor elements in each of the minerals. A few significant elements in the mineral analyses are: Sc, Y, La, Ce, Nd, Ti, V, Cr, Mn, Fe, and Co.

Comparison of analytical results obtained for the Tertiary dike rocks with those obtained for other Front Range igneous rocks of pre-Cambrian and Tertiary ages (not dikes) revealed definite points of difference. It is the author's firm belief that the spectrographic method, when properly applied, will prove a definite aid in correlation problems involving igneous rocks anywhere.

X-RAY EXAMINATION OF CRYSTALLINE FORMS OF ANHYDROUS SODIUM STEARATE AT ROOM TEMPERATURE

ALEXANDER DE BRETTEVILLE, JR.

There are three known polymorphic forms of sodium stearate. If sodium stearate is prepared from stearic acid, it exhibits the monoclinic B form. The rhombic form can be obtained from the B form by slow crystallization from a 1% solution in 95% alcohol and

air drying. The monoclinic A form is produced by heating the rhombic form above 54°C. and cooling. The processes are represented diagrammatically:



A sample of thallos palmitate representing yet another monoclinic form, to which we will refer as monoclinic C, was given to us by Dr. A. S. C. Lawrence of Cambridge, England. A sample of rhombic soap was also given to the author by J. Stauff of Berlin and found to be identical with the Eastman above and with J. Stauff and P. Thiessen's results.¹ The monoclinic A form does not agree with the results of Stauff and Thiessen and a different equation for the indices is given. The tilt of the chain is 62.9° for the A form.

The monoclinic B form is the most stable and is shown to be due to a shortening of the *c* axis by 2.4 Å due to a rearrangement of the dipole COONa group. There is a shift of alternate molecules of 180° around the *c* axis. The tilt of the carbon chain for the monoclinic B form is assumed the same as the monoclinic A form, namely 62.9°. This is supported by two other indirect experimental measurements.

¹ *Zeit. Physik. Chemie (A)*, p. 397, 176 (1936).

THE UNIT CELL AND SPACE GROUP OF CLAUDETITE, As₂O₃

M. J. BUEGER

The unit cell and space group of the Jerome, Arizona, claudetite has been determined. The diffraction record consists of one rotation photograph and the zero, first, and second level photographs taken by the method of de Jong and Bouman. The diffraction symmetry is clearly 2/*m*. The lattice is simple monoclinic and the reduced cell has the dimensions:

Absolute	Ratio
<i>a</i> = 5.25 Å	.408
<i>b</i> = 12.87	1.
<i>c</i> = 4.54	.353

This cell contains approximately 4As₂O₃. The diffraction symbol is 2/*mP*2₁/*n*, which uniquely fixes the space group as *P*2₁/*n* (C_{2h}⁸).

STRUCTURAL RELATIONS BETWEEN HIGH- AND LOW-CHALCOCITE

M. J. BUEGER AND NEWTON W. BUEGER

It has been recently shown¹ that what has passed for high-chalcocite is really digenite, Cu₉S₅. In order to investigate the character of the true high-chalcocite, a delicate furnace was designed to maintain single crystals at a definite elevated temperature on a Weissenberg apparatus.² With the aid of this, the structural characteristics of the Bristol chalcocite were investigated at 112°C. by the equi-inclination Weissenberg technique. The diffraction symmetry of true high-chalcocite is 6/*mmm*. It is based upon a hexagonal lattice described by the following cell:

$$\begin{array}{ll} a = 3.89 \text{ Å} \\ c = 6.68 & c/a = 1.717 \end{array}$$

This cell contains 2Cu₂S. The diffraction symbol is 6/*mmmC* - / - - *c*. This embraces space groups *C*62*c*, *C*6*mc*, and *C*6/*mmc*. It is likely that the last is the correct one. This symmetry, the cell constants, and the thermal evidence¹ for the disorder transformation from low- to

¹ Buerger, Newton W., The chalcocite problem; *Ec. Geol.*, **36**, 19-44 (1941).

² See abstract by Newton W. Buerger, *Weissenberg controlled-temperature technique*.

high-chalcocite suggest a structure composed of sulfur atoms in hexagonal close-packing, within whose interstitial channels copper atoms are flowing.

The structure of the same chalcocite was investigated at room temperature by means of the usual equi-inclination Weissenberg technique and also by the de Jong and Bouman method using the equal-cone technique. Low-chalcocite has the diffraction symmetry *mmm*. It is based upon an *A*-centered orthorhombic cell of the following dimensions:

absolute	ratio
$a = 11.90 \text{ \AA}$.4365
$b = 27.28$	1
$c = 13.41$.492

This cell contains 96 Cu₂S. The diffraction symbol is *mmmAb* ---. This embraces space groups *Abmm* and *Ab2m*. It is likely that the latter is the correct symmetry, because the holohedral symmetry *Abmm* contains a mirror which could not be derived from the more symmetrical high-chalcocite, which is a very unlikely possibility. Because of the strong resemblance between the *x*-ray photographs of the high- and low-chalcocite, it is likely that the latter is based upon hexagonal close-packed sulfur atoms within whose interstices the copper atoms have fixed positions. The matrix of the transformation from high-chalcocite to low-chalcocite is

$$\begin{vmatrix} 3 & 0 & 0 \\ 0 & 4 & 0 \\ 0 & 0 & 2 \end{vmatrix}, \text{ modulus } 24.$$

The multiplicity of the superstructure of the low-chalcocite is accordingly 24.

A TEMPERATURE-CONTROLLED X-RAY POWDER CAMERA

M. J. BUERGER, NEWTON W. BUERGER AND FRANK G. CHESLEY

An *x*-ray powder camera has been designed and constructed for investigating various systems or substances under the influence of controlled elevated temperatures. The main features of this instrument embody facilities for disassembly in stages. The light-tight film-holding device is completely removable without disturbing the thermal environment of the specimen. This feature permits the taking of an indefinite series of photographs of a specimen under controlled rising or falling temperature conditions without heat treating the specimen. The camera itself is of the usual 57.3 mm. diameter and is provided with a film expansion device which assures contact of the film with the camera body. The heating unit may be removed without disturbing the position of the sample. This feature permits the instrument to be used as an ordinary powder camera. A small, efficient, and sensitive electric furnace maintains the specimen under investigation at an elevated temperature by means of radiation insulation. A water cooling system protects the film against undesirable heat effects from the electric furnace. The calibration of the furnace is accomplished by systematically taking a series of photographs of selected high-low polymorphic inversions. The advantage of this method of calibration is that it gives a rather precise indication of the temperature at the particular spot where the sample is bathed in the incident *x*-radiation; therefore the actual temperature at the origin of diffraction is measured. The camera has been successfully employed in studying heat effects on salts, organic materials, and mineral substances and has been operated at temperatures near 600°C.

WEISSENBERG CONTROLLED-TEMPERATURE TECHNIQUE

NEWTON W. BUERGER

A heating accessory has been developed which permits the investigation of single crystals at any desired temperature. The heating chamber is built into a tube which slips over the spindle housing of a Weissenberg *x*-ray goniometer. This in no way interferes with the

normal flexibility of the instrument, so that cell constants and structures can be determined by the equi-inclination method at controlled elevated temperatures. This technique has been applied successfully to high chalcocite. The attachment serves a dual purpose, since it makes possible an improved method of recording powder photographs of a substance which is being subjected to various temperatures.

X-RAY EVIDENCE OF THE EXISTENCE OF THE MINERAL DIGENITE, Cu_9S_8

NEWTON W. BUERGER

X-ray studies of the system Cu_2S – CuS have shown the existence of the compound Cu_9S_8 as a separate phase. The diffraction pattern produced by this intermediate compound corresponds with that obtained from a type specimen of digenite, a mineral apparently among Dana's discredited species. There is no longer room for doubt that the mineral exists, and is indeed the familiar "isometric chalcocite." This is obvious from a comparison of the diffraction pattern of digenite, or Cu_9S_8 , with those obtained by Kerr on three specimens of "isometric chalcocite" from Kennecott, Alaska, and by Kurz on the same material; the patterns are identical. Since digenite is in fact a rather common mineral occurring with chalcocite and other copper ore minerals, it must be re-established as a species.

ORIGIN OF SULPHIDES IN THE NICKEL DEPOSITS OF MOUNT PROSPECT, CONNECTICUT

EUGENE N. CAMERON*

Nickel-bearing deposits occur at a number of places in the intrusive complex of Mount Prospect, near Litchfield, Connecticut. The ores are noritic and pyroxenitic rocks containing varying amounts of pyrite, pyrrhotite, pentlandite and chalcopyrite. The rocks are largely free from characteristic hydrothermal alteration products. This feature and the textural relations of sulphides to silicates in the ores have previously been taken to indicate that the sulphides are of magmatic or late magmatic origin.

A detailed study of the intrusive complex has furnished field data and new microscopic evidence which relate to the problem of sulphide origin. Mapping has shown that the principal ore-bearing rocks comprise intrusives of three different types: mafic norite, norite and hypersthene pyroxenite, intruded in that order. The nickel deposits are concentrations of sulphides at or near the margins of these intrusives. Apart from the sulphides, the rocks consist essentially of hypersthene, clinopyroxene, plagioclase, hornblende and biotite. Indications have been found that hornblende, at least in part, and biotite developed after solidification of the rocks. The sulphides appear to have been introduced later and to have formed chiefly by fracture filling and by replacement of the various silicates. No specific conclusions have been reached as to time of sulphide deposition for the deposits as a group, but the presence of introduced sulphides in fine-grained dikes cutting mafic norite and norite at two deposits suggests that a considerable interval elapsed between solidification of the latter rocks and development of sulphides.

* Presented through the Geological Society of America.

ORBICULAR GABBRO FROM BLACK BUTTE, LOS ANGELES COUNTY, CALIFORNIA

IAN CAMPBELL

Black Butte is a small, isolated desert dome in northeastern Los Angeles County, California. A dark hornblende gabbro forms a capping; adamellite, intrusive in the gabbro, forms the lower portions of the butte.

The gabbro is somewhat variable in texture and composition. One facies, of very limited development, shows pronounced orbicular structure. The "orbicules" are ellipsoidal, with median diameters of six to ten centimeters. Their concentric development is well marked.

It consists of a nucleus of medium-grained hornblende gabbro; surrounding this is a shell dominantly of hornblende and fine-grained magnetite; succeeding this is a zone, varying slightly in mineral proportions in different orbicules, but characterized throughout by fine grain and composed of thin shells of labradorite-magnetite, hornblende-magnetite and labradorite-sphene-magnetite; last is an outermost shell of medium-grained hornblende. The external matrix of the orbicules is hornblende gabbro, similar to the nucleus. Except for a rude radial arrangement of hornblende in the outer layer, the minerals of the orbicules show no obvious orientation.

Feldspar is calcic labradorite showing little change in composition throughout the rock. Hornblende is green, uraltic, and commonly contains residuals of colorless pyroxene. Much of the magnetite is believed to be early, some may be deuteric. It is frequently rimmed by sphene. None of these features seems to be related to position within an orbicule.

Of the many hypotheses that seek to explain orbicular structures that of Loewinson-Lessing and Vorobjeva seems most nearly to fit the present case.

X-RAY CRYSTALLOGRAPHIC STUDIES UPON ETIOPORPHYRIN-1

CHARLES L. CHRIST AND DAVID HARKER

Goniometric and *x*-ray measurements show that etioporphyrin-1 has the point group $2/m$. Oscillation photographs with $\text{CuK}\alpha$ -radiation of the single crystals yield the structure: monoclinic, $a_0 = 10.3 \pm 0.1$ Å; $b_0 = 19.5 \pm 0.1$ Å; $c_0 = 6.75 \pm 0.05$ Å; $\beta = 98^\circ \pm 1^\circ$; $Z = 2$ molecules $\text{C}_{32}\text{H}_{38}\text{N}_4$; *d*. (*x*-rays) 1.17; space group $P2_{1/c}$.

The probable structure of the *porphin* molecule, based on the data of organic chemistry¹ and on the structure of phthalocyanine² is discussed. A model for the etioporphyrin-1 molecule is proposed and this is tested by a combination of trial and error and Fourier series methods. As a result of this testing it is shown that the model proposed is in agreement with the data at hand, but that these are insufficient to test the details of the structure.

¹ Corwin and Quattlebaum, *Jour. Am. Chem. Soc.*, **58**, 1081 (1936).

² Robertson, J. M., *Jour. Chem. Soc.*, 1195 (1936).

CLAY MINERALS IN RECENT MARINE SEDIMENTS

ROBERT S. DIETZ

A study was made of the clay fraction of 39 sediment samples from the various oceans of the world.

Particle size analyses of these clays showed that the clay particles of the red clay samples are coarser than those of the green and blue muds which in turn are usually coarser than clays in tidal estuaries, bays, inland seas, river sediments and soil clays. Consequently, marine clays probably undergo a post-depositional increase in grain size.

X-ray and petrographic analyses showed that the three common groups of clay minerals present in soils, namely, illite, kaolin, and montmorillonite are also the main constituents of marine clays. Although illite and kaolin are present in all of the samples, illite usually predominates. Small amounts of montmorillonite were found in the near shore sediments but were not detected in those from the deep sea.

Kaolin and montmorillonite were found to have formed on the sea floor by the alteration of the feldspars in granite. Other considerations suggested that illite may also form by the alteration of some primary minerals and, especially, by the alteration of montmorillonite. This latter change involves the absorption into montmorillonite of potassium from sea water. Such a process of illitization might account for (1) the post-depositional increase in the size of clay particles in marine clays, (2) the general absence of montmorillonite in marine clays, (3) the absence of montmorillonite in most shales, and, (4) the low potassium to sodium ratio in sea water as compared to that of river water. Illitization is probably an

extremely slow process which goes to completion only in areas of slow deposition. The formation of the illite mineral, glauconite, may be a special case of the process.

DERIVATION OF THE 32 POINT-GROUPS

J. D. H. DONNAY

(1) Symmetry is redefined. A crystal is said to lack, or to have, symmetry, according as all, or not all, directions in the crystal are singular and polar.

(2) It is proved by elementary mathematics that symmetry operations are of two kinds only: rotation and rotatory-inversion.

(3) The general theorems on symmetry are recast in the form of eight propositions conforming with the concept of inversion axes (instead of the previous reflection axes or planes of alternating symmetry).

(4) A simplified derivation of the 32 point-groups, following the dichotomous principle, is based on the above eight theorems. The elements considered are the axes (rotation axes: 1, 2, 3, 4, 6; inversion axes: $\bar{1}$, $\bar{6}$), the center ($\bar{1}$), and the mirror (m). They are the independent symmetry elements, save $\bar{6}$, which is added for convenience. The method consists in establishing first all the axes and possible combinations of axes, then in combining them with the center and mirrors.

(5) The derivation claims the following advantages: (a) Foremost it leads to the international (Mauguin) symbols. (b) Although based on simple mathematical prerequisites, it skips no single step. (c) The 32 groups are established with a minimum of duplication. (d) They are derived in such a sequence as to fall naturally into the 6 crystal systems, the 7 lattice symmetries, and the 11 "Laue symmetries." (e) The derivation brings out the parallelism of the two cases where a unique singular axis is an inversion axis with an even period ($\bar{4}$ and $\bar{4}2m$ on the one hand, $\bar{6}$ and $\bar{6}2m$ on the other).

THE MORPHOLOGICAL EXPRESSION OF TETRAGONAL SPACE-GROUPS

J. D. H. DONNAY

The 68 tetragonal space-groups are distributed among 31 morphological aspects: 23 in the $P-C$ lattice and 8 in the $I-F$ lattice.

In the *initial pattern* of the P lattice (no glide-planes, nor screw-axes), every zone is simple with unit face dominant; all indices are co-prime. The base may have its indices doubled or quadrupled by a screw axis (4_2 or 4_1). The prism (010) may be doubled by a 2_1 -axis. A double zone for the ($hk0$) or ($0kl$) faces indicates an n glide-plane; the zone of the ($0kl$) faces may remain simple, while its dominant is shifted toward $c(001)$ or $b(010)$, indicating respectively a c or a b glide-plane; the zone of the (hhl) faces may have (112) dominant, the shift toward $c(001)$ indicating a c glide-plane.

In the *initial pattern* of the I lattice, the zones of the ($hk0$) and ($0kl$) faces are doubled, with (110) and (011) dominant; the zone of the (hhl) faces is simple, with (112) dominant; the zone of the (hkh) faces is simple, with (121) dominant; two forms are doubled, (002) and (020). The base may be quadrupled by a 4_1 -axis. The zones of the ($hk0$) and ($0kl$) faces may become simple with all indices doubled, indicating respectively an a or a c glide-plane. The zone of the (hhl) faces may become double, (112) remaining dominant; this indicates a d glide-plane.

Similar rules can be stated (in the other orientation) for the C and F lattices.

PEGMATITES NEAR CUSTER, SOUTH DAKOTA*

D. JEROME FISHER

There are hundreds of pegmatite dikes in the southern Black Hills (Custer County), southwest of the famous Keystone district. Although by no means limited to this strip,

* Work done under the auspices of the South Dakota Geological Survey.

these are especially common in a belt of mica schist between Custer and Pringle, where locally they appear as a series of steeply-dipping en echelon walls, like some great natural tank trap. cursory field examination of a dozen of these dikes indicated that they run the gamut from nearly simple intrusions of microcline-quartz pegmatites to complex albitized examples that have undergone much replacement. This paper reports on the results of detailed field mapping and laboratory study of three of these dikes (Tip Top, High Climb, and Beecher Lodes), substantiating this point of view.

CHROMITE DEPOSITS OF THE PHILIPPINE ISLANDS*

DEAN F. FRASCHE

The chromite deposits of the Philippines occur in isolated masses of ultra-basic rocks which are in general found along the eastern and western borders of the Island group. The ultra-basic rocks are highly serpentinized and are difficult to distinguish in the field but petrographic studies reveal them to be composed essentially of three intergrading rock types, dunite, saxonite and pyroxenite. Of these three types, saxonite occurs in greater volume than either dunite or pyroxenite. Varying amounts of chromite are found in the different rocks but the known commercially important deposits appear to be confined entirely to the serpentinized dunite. Locally in the Zambales area, gabbro and diorite intrude the chromite deposits, but these less basic rocks appear to be confined to the refractory grade ore bodies. The chromite is considered to be genetically related to the dunite and is probably of early magmatic origin.

Although chromite occurs in commercial quantities on several of the islands, the largest deposits are found in Zambales Province, Luzon. The individual deposits vary greatly in size, ranging from a few hundred to more than ten million metric tons. The grades of chromite now being produced in the Zambales area are classified according to their industrial uses, namely, metallurgical ores, chemical ores and refractory ores.

Philippine reserves of chromite of all grades are estimated to be 10,890,500 metric tons. Of this total 10,120,000 metric tons are refractory grade, 450,500 tons are chemical grade, and 320,000 tons are metallurgical or submetallurgical grade.

* Presented through the Society of Economic Geologists.

MINERALOGY OF PINCHI LAKE

A. C. FREEZE

Recent studies at Pinchi Lake show the existence of a late Paleozoic-early Mesozoic mountain range previously unrecognized in any part of British Columbia.

Detrital chromite derived from post-Sakmarian serpentines and found in sediments of Upper Triassic age indicates a period of orogeny accompanied by a period of erosion between the early Permian and the late Triassic.

Glaucophane is widespread and appears to be confined to early Permian rocks suggesting a closer relationship to the pre-Upper Triassic-post-Sakmarian metamorphism than to later Mesozoic-early Tertiary disturbances. The mineral is present in rocks of both sedimentary and igneous origin and probable mixtures of both.

The glaucophane occurs in an area containing serpentinized peridotite, but shows no distinct spatial relationship to these intrusions. In the sequence of minerals developed during the metamorphism, hornblende, clinozoisite, chlorite, muscovite, and vein quartz precede glaucophane, and glaucophane crystallization is succeeded by veins of oligoclase, calcite, late chlorite, and (?) allanite.

An introduction of soda is considered necessary to account for the distribution and amount of glaucophane. Later calcite oligoclase veinlets lend support to this hypothesis.

The cinnabar mineralization and accompanying mineral suite are much younger (post Upper Triassic) than the glaucophane and related minerals.

BISMUTH-OSCHER, BISMUTITE, BISMUTOSPHAERITE, BASOBISMUTITE, BISMITE AND BISMOCILITE

CLIFFORD FRONDEL

Forty-one specimens from 34 localities of bismutite, bismuth-oscher and bismutosphaerite were examined by x-ray, optical and chemical methods. Bismutite supposedly is a hydrated bismuth carbonate but all of the specimens examined contained only non-essential water and proved to be identical with bismutosphaerite (Bi_2CO_5). Basobismutite also is identical with Bi_2CO_5 . So-called bismuth-oschers that afforded both Bi and CO_2 tests all proved to be Bi_2CO_5 ; others were bismuth arsenate, cerussite, etc. Artificial hydrous bismuth carbonates and bismutite give a smooth dehydration curve to about 290° , where the CO_2 is lost and $\alpha\text{-Bi}_2\text{O}_3$ remains. Efforts to synthesize definite hydrates were unsuccessful.

The identity of bismite, supposedly Bi_2O_3 , long has been uncertain. Twenty-two specimens labelled bismite from 15 localities were examined. Neither $\text{Bi}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ nor any of the four polymorphs of Bi_2O_3 were represented. $\text{Bi}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, however, probably occurs in nature (Schaller (1911) and others). Of the specimens examined, 8 were Bi_2CO_5 , 2 were bismoclite, and 4 were a new carbonate of Bi and Ca. The latter mineral occurs very sparingly at Schneeberg, Saxony, as tiny yellow tetragonal plates, optically negative, $\omega = 2.13$; this mineral was recognized and partly described by Arzruni and Thaddéeff (1899). Bismoclite, BiOCl , hitherto known only from South Africa, is described from two new localities: Bygöo, New South Wales, and Tintic, Utah. The bismite reported from Goldfield, Nevada, also is bismoclite (Schaller. priv. comm., 1940). Reported syntheses of $\text{Bi}_2\text{O}_3 \cdot \text{H}_2\text{O}$ (or $\text{BiO}(\text{OH})$) and some other hydrates could not be verified; most are $\alpha\text{-Bi}_2\text{O}_3 \cdot n\text{H}_2\text{O}$.

PLEONASTE FROM MINERAL COUNTY, NEVADA

VINCENT P. GIANELLA

As pleonaste has not been reported from Nevada, other than in thin sections, its recent discovery in macroscopic crystals is of interest. This occurrence is in the Garfield Hills in Mineral County, Nevada, about one and one half miles southwest of Kinkead siding. The mineral has developed in roughly lenticular masses up to two feet wide and fifty feet long in dolomite of the Upper Triassic Luning formation. The color is dark green to black and it is found in finely granular aggregates as well as in well-formed octahedra some of which are four, or more, millimeters in length.

MINERALIZATION OF THE AJO COPPER DISTRICT, ARIZONA*

JAMES GILLULY

The new Cornelia orebody at Ajo is a deposit of chalcopyrite with subordinate bornite and other minerals disseminated in a mass of quartz monzonite porphyry of early Tertiary (?) age. Petrographic study shows that the orebody lies in part of the porphyry with a peculiar groundmass texture that is believed to date from a time prior to consolidation. Pegmatites of probable replacement origin were formed later, and the monzonite surrounding them was heavily impregnated with finer-textured potash feldspar and quartz. Sulphide impregnation, which followed, is heaviest in and near the pegmatites, and fades out into a zone of sericitization peripheral to the zone of feldspar impregnation. The mineralization is believed to have been by an unbroken continuation of magmatic evolution into a hydrothermal stage. No discontinuities are recognized in the sequence of alterations that linked

* Presented through the Geological Society of America.

the magmatic stage with that of sulphide mineralization, although specular hematite, which is very abundant, seems clearly governed by different controls, and may record a discontinuous-pneumatolytic-stage. It is uncertain, but appears probable that sulphide mineralization and hydrothermal alteration reverted to their former controls after the period of specularite formation.

Weathering of the deposit has taken place in two stages: an earlier, during which there was notable downward enrichment, and a later, during which the copper was oxidized essentially in place. Between the two periods, the block containing the deposit was tilted about 60°. No satisfactory explanation of the different behavior during the two erosion cycles has been discovered.

AUTORADIOGRAPHY OF ORES

CLARK GOODMAN AND GEORGE A. THOMPSON

Using stray slow neutrons from the M. I. T. cyclotron on elements having large nuclear cross-sections for (n, γ) reactions and yielding radioactive isotopes of convenient half-periods, autoradiographic studies of a number of ores have been made. The locus and relative concentrations of these elements in the constituent minerals is determined by placing polished sections of the activated ores in direct contact with photographic film. The source of the effective β -radiation is ascertained from the decay rate and intensity of the activity. Manganese, gold, cadmium and phosphorus bearing ores have been studied by this method. Further investigations are in progress with the purpose of extending the method to other elements, of making the method quantitative, and of applying the method to thin sections.

DIFFERENTIAL THERMAL ANALYSIS OF CLAY MINERALS*

RALPH E. GRIM AND RICHARDS A. ROWLAND

Differential thermal curves are presented for a large number of clay minerals and related silicates. The characteristics of the thermal curves of illites, kaolinites, and montmorillonites, and other clay minerals are discussed. The significance of the thermal data with regard to the lattice structures of the clay minerals, and to the changes they undergo when subjected to heat is considered. On the basis of these considerations certain clay mineral names are discredited.

Thermal curves are presented also for natural and artificial mixtures of clay minerals, and the use of differential thermal curves for identifying clay minerals and estimating their relative abundance in conjunction with x-ray, optical, and chemical methods is critically analyzed.

* Published with the permission of the Chief, Illinois State Geological Survey, Urbana, Illinois.

SODIUM MICA SYNTHETIZED

JOHN W. GRUNER

Since it is relatively easy to synthesize muscovite in weak HCl solutions at 400°C., it was thought that the existence of paragonite might be proved or disproved by attempting its synthesis in the laboratory. The bomb experiments were made at 400°C. in 1/10 N HCl solutions. $\text{Al}(\text{OH})_3$, hydrated silica, and NaCl (the latter in large excess) were used. The resultant product contained two minerals as found by x-rays, paragonite and boehmite. Paragonite was much more abundant. The height of its unit cell is 19.32 Å as compared with the 20.0 Å for muscovite. Its width (b_0) is 8.90 Å. These values agree well with the expected magnitudes. An analysis for Na_2O of the carefully washed sample gave 5.4%, which is $\frac{2}{3}$ of the theoretical value of 8.1%. Since an unknown amount of boehmite was mixed with

the paragonite, the deficiency of Na is not very large, especially when compared with natural Na micas.

DIAMONDS IN THE WIRE DRAWING INDUSTRY

PAUL L. HERZ

Wire drawing dies made from diamond crystals are superior to other types of dies for drawing metallic wire. The price of the rough diamond, die manufacturing costs, diameter of the drawn wire, kind of wire, and allowable tolerances are related factors which, in any given operation, determine whether diamond should be used in preference to other die material.

The kind of rough material most suitable for dies and its desirable and undesirable characteristics are discussed. Limitations in the use of diamond are pointed out.

The peculiar problems presented in the manufacture and use of dies of capillary diameter are stressed.

APPARATUS FOR DIRECT MEASUREMENT OF LINEAR STRUCTURES

EARL INGERSON

A compass is mounted with a graduated semi-circle that is weighted so that it remains vertical, and the compass is provided with a weighted pointer that keeps it horizontal. This arrangement is swung on pivots in a frame that has a straight edge that can be placed on, or parallel to, a linear structure in the field. Direction of pitch is read on the compass, and angle of pitch is read on the vertical circle. Dip and strike of planar structures can also be measured with the apparatus.

ORIGIN OF SHAPES OF QUARTZ SAND GRAINS

EARL INGERSON AND JOSEPH L. RAMISCH

Wayland concluded from a study of the St. Peter and Jordan sandstones that "it is probable that clastic quartz grains are longer and harder in the direction of the optic axis."

To check this conclusion three sets of experiments have been carried out, with the following results:

- 1) No relation between c -axes and elongation of fragments could be established for crushed quartz.
- 2) Quartz grains from weathered (but undisturbed) quartzose rocks show a tendency to be elongate parallel to prismatic and rhombohedral faces.
- 3) Abrasion tests on oriented prisms show that quartz is harder on faces parallel to the c -axis than normal thereto.

It is concluded that the elongation of quartz sand grains parallel to the c -axis is due to original shape rather than to differential abrasion during transport.

CUTTING OF GEM DIAMONDS

LAZARE AND LEO KAPLAN

With the closing of European sources of supply of finished diamonds, unusual demands have been made upon the American cutting industry. Labor costs have risen with unusual rapidity. The price rise in rough material and the changes made in the channels of distribution are considered.

Because of the disproportionate rise in labor costs the price rise in the finished products has been most pronounced in smaller diamonds. The situation in the case of melee is given special attention. The role of the refugee as a source of supply is also discussed.

RADIOACTIVE AUREOLES AROUND SOME ORE DEPOSITS

NORMAN B. KEEVIL

Mineral deposits are sometimes less, sometimes more radioactive than country rock. When the ore body is relatively high in activity, concentrations of radioactive material in the vicinity of the deposit have been observed in some instances. At Gilman, Colorado, where a series of samples collected during a Lundberg geophysical survey were examined, the activity was observed to be higher near radioactive ore and to decrease in concentration away from the ore body. Some of the activity appeared to be due to diffused radon, but spectrochemical concentrations of silver, copper, lead, and zinc associated with the radioactivity suggested that much of the radioactive material was introduced during mineralization. The results suggest that sample analysis may be useful in indicating proximity to ore in some instances.

ORIGIN OF THE QUARTZ DEPOSIT AT FAZENDA PACÚ, BRAZIL

PAUL F. KERR AND ALBERTO ERICHSEN

The deposits of crystal quartz now being worked at Fazenda Pacú, Minas Geraes, Brazil, provide the most important source of commercial crystals in Brazil. Crystals occur in a deeply weathered zone along the contact between the Archean and overlying Silurian sediments. Decomposition of the matrix obscures direct evidence of origin, but the quartz is believed to have been formed originally by coarse crystallization in veins. In addition to deposits formed in situ, clay and gravel deposits occur in which the gravels are rounded quartz crystals.

BONDED DIAMOND WHEELS

A. A. KLEIN

The growth in the use of cemented tungsten and tantalum carbide tools for shaping metals has resulted in the development of grinding wheels containing diamond grain bonded with resinoid or metal bonds. These function to form, shape and sharpen the cemented carbide article. Such operations were economically quite impossible to accomplish with the usual bonded silicon carbide wheels. Since diamond wheels have become commercially available other interesting uses have developed.

This presentation will discuss briefly the kind of diamond used and its preparation, the manufacture of bonded diamond wheels, and their applications in industry.

DIAMOND PRODUCTION

SYDNEY H. BALL

In the past generation diamond production has undergone one of its major cyclical changes in the long history of the diamond industry. From 1907 to 1930, important alluvial diamond fields were successively found in the Belgian Congo, South West Africa, Angola, Gold Coast and Sierra Leone. These virgin fields have, on the average, low operating costs and their production has expanded rapidly. The pipe mines of South Africa, which 25 years ago were the dominant producers, are now, due to economic factors in the industry, shut down.

Production today is, by weight, over 14,000,000 carats worth some \$31,000,000, as opposed to an average of 7,200,000 carats worth about \$75,000,000 for the four years 1927 to 1930—a change mainly due to the large bort production of a single Belgian Congo company. The weight of fine cuttable material is today but 70% of that of ten years ago.

Twenty years ago all of the African production came from the South African pipes or from alluvial deposits derived from them; these intrusions are of Cretaceous age. Today about 75% of Africa's production comes from alluvial deposits derived from sources of pre-Cambrian age.

AMERICAN SYNTHETIC RUBIES AND SAPPHIRES

EDWARD H. KRAUS AND CHESTER B. SLAWSON

The chemical, physical, and optical properties of American-made boules and their relationship to the strained conditions within the boules are discussed.

PARAGENESIS OF THE McDONALD PEGMATITE NEAR HYBLA, ONTARIO

KENNETH K. LANDES

The McDonald spar mine is in Monteaule township, Hastings County, Ontario, about 2 miles southeast of Hybla and 10 miles north of Bancroft. The district is noted for its great variety of rocks, and the McDonald deposit for the radioactive minerals found there. The main pegmatite at the McDonald mine is a dike up to 50 feet in width and several hundred feet in length. It is in large part a truly giant granite, consisting of huge masses of feldspar and quartz. In parts of the dike are large bodies of soda feldspar (with subordinate smoky quartz), and coarse pink or salmon colored calcite. Invariably the rare-earth minerals allanite and cyrtolite are with the soda feldspar, and ellsworthite and zircon with calcite. The calcite group is definitely later in age than the soda feldspar group, as both feldspar and smoky quartz are traversed by calcite veins. The paragenesis appears to be: (1) crystallization of the main granite pegmatite; (2) an early hydrothermal stage during which soda feldspar and associated minerals were deposited; and (3) a late hydrothermal stage during which calcite, ellsworthite, and zircon were formed. Contamination of the pegmatite magma by limestone is suggested.

THE SIZE OF THE UNIT CELL AND THE COEFFICIENT OF EXPANSION OF HIGH-CRISTOBALITE

JOSEPH S. LUKESH

The length of the axis of the unit cell of high-cristobalite was found on artificial material to be $7.031, \text{\AA}$ at 275°C . and $7.044, \text{\AA}$ at 480°C . This corresponds to an increase in length per unit length per degree Centigrade of 8.53×10^{-6} , which is of the order of magnitude of the two coefficients of quartz. The values were obtained from back reflections on films taken in the camera described by Buerger, Buerger and Chesley,¹ and a modified Bradley and Jay extrapolation was employed in the computations. The values for the axial length are appreciably smaller than those reported by Wyckoff (7.12\AA at 290°C .) and by Barth (7.16\AA at 500°C .). The discrepancy may be due to any or all of three causes: material used, previous thermal history of the sample, or technique used in measurements.

¹ See abstract, *A temperature-controlled x-ray powder camera*.

THE UNIT CELL AND SPACE GROUP OF KALIOPHILITE

JOSEPH S. LUKESH AND M. J. BUERGER

An x-ray investigation has been made of kaliophilite, KAlSiO_4 , using a de Jong-Bouman type camera. The hexagonal nature of the cell and the lattice constants as determined by Bannister have been confirmed. The reciprocal lattice was recorded directly for the zero, 1st and 2nd layers for both c and a axis rotations. The only systematic absences were found to be $(000l)$ halved when l was odd. The diffraction symbol is $6/mmmC6_3/- - -$. The only possible space group is $C6_2 (D_6)$. Tests were made for both piezo- and pyroelectricity, and in both cases positive results were obtained. The results for pyroelectricity, however, were less conclusive than for piezoelectricity and may have been due to a pseudo-pyroelectric effect resulting from strains in the crystal.

The lattice constants of the hexagonal unit are:

$$\begin{aligned} a &= 26.94 \text{\AA} \\ c &= 8.55 \text{\AA} \\ c/a &= 0.317 \end{aligned}$$

Considering the specific gravity to be 2.60 and the formula to be ideally KAlSiO_4 , there are 54 formula weights per unit cell.

Work is being continued to determine the structure.

GRIPHITE, A HYDROPHOSPHATE GARNETOID

DUNCAN McCONNELL

Griphite is cubic and its structure is similar to that of garnets. The unit cell contains $8[(\text{Na}, \text{Al}, \text{Ca}, \text{Fe})_3 \text{Mn}_2(\text{PO})_{2.5}(\text{OH})_2]$ and represents a complex example of the formula $\text{X}_3\text{Y}_2(\text{ZO}_4)_{3-m}(\text{OH})_{4m}$, the latter being a variation of $\text{X}_3\text{Y}_2(\text{ZO}_4)_3$ which is necessary to accommodate the hydro-garnets and plazolite. The cell edge is 12.26 \AA and ρ is 3.399. An alternate formula is suggested and cannot be eliminated as a possibility, namely, $8[(\text{Na}, \text{Ca}, \text{Fe}, \text{Mn})_3 (\text{Al}, \text{Mn})_2(\text{PO}_4)_{2.5}(\text{OH})_2]$. The space group could not be determined but appears to have lower symmetry than that of garnet ($\text{O}^{10}_h = \text{Ia}\bar{3}d$).

Garnetoids are substances other than simple silicates which have structures similar to garnets, including: berzeliite, Ca-Al- and Ca-Fe-hydrogarnets, plazolite and griphite.

NOMOGRAPHIC SOLUTIONS OF OPTIC ANGLE FORMULAE

JOHN B. MERTIE, JR.

Nomograms are presented herewith for the solution of several well-known formulae, that are used in the measurement of optic angles. To solve for any one of the four variables V , α , β , and γ , when three of them are known, a grid type nomogram has been prepared; and a similar chart has been drawn to show the relationships between the variables E , α , β , and γ . Two nomograms are also presented for the solution of the equations $\sin E = \beta \sin V$ and $d = k \sin E$ (Mallard's formula). The method of preparing these charts is outlined, and their uses given.

GOLD MINERALIZATION IN MINOR IGNEOUS INTRUSIONS*

WILSON W. MOORHOUSE

The association of gold mineralization with or in porphyry dikes and bodies is known in many parts of the Canadian shield. This relationship has frequently been considered to be purely structural or genetic only in the sense of derivation from the same magmatic source. Evidence of a much more intimate connection is given from an occurrence of auriferous pyrite as disseminations and in quartz-carbonate veins in albitite porphyry in Bryce township, Ontario. The porphyry is in part a normal dike, in part a replacement of associated schists. Stringers extending into the schists are enclosed by a zone of albitization which resembles the porphyry itself. This, with other examples from the same area, is believed to indicate that replacement and intrusion by albitic material were accompanied by the gold-pyrite mineralization. Comparisons are given with other gold deposits associated with porphyry and albitite dikes and bodies in Canada.

Auriferous quartz-sulphide mineralization which has been discovered in small altered dioritic bodies in relationships of the veins to these intrusives suggests a rather close genetic connection. Reference is made to comparable gold deposits described in the literature.

* Presented through the Geological Society of America.

SOLUBILITY OF SOLIDS IN "GASES" OR "VAPORS"

GEORGE W. MOREY AND EARL INGERSON

The transport in significant quantity of solid material by means of a gas or vapor at high temperature and pressure is dependent on solubility of the solid in the vapor. By this

is meant that in unit volume of the vapor the content of solid is greater than corresponds to its own vapor pressure at the temperature and total pressure under consideration. In our work we have found transport and deposition of corundum, rutile, sillimanite, quartz and amorphous silica by water at temperatures from 500 to 1000°, and at pressures from 3000 to 15,000 pounds. These experiments and products will be described.

The consideration of problems of solubility of solids in vapor requires rigid definition of the terms "gas," "vapor," and "fluid" as applied to phases coexisting in several component systems under conditions in which definitions which are logical and complete for a one component system no longer are applicable. Definitions of "gas" and "vapor" are proposed.

The further discussion of the problem of the solubility of non-volatile solids in a vapor will be made with the aid of diagrams illustrating the variation of temperature, pressure, and composition in binary systems in which different types of critical end-points are assumed.

* Presented through the Geological Society of America.

CONTRIBUTIONS TO THE CRYSTALLOGRAPHY OF HUREAULITE

JOSEPH MURDOCH

Hureaulite formed close to the end of a sequence of phosphate minerals at Pala, California, shows measurable crystals. These crystals are unusually good, and measurements warrant some modification of the crystallographic elements. The amended values correspond very closely to those for pure synthetic crystals. It is suggested that the Dana setting be retained, but that the *c* axis be doubled, resulting in a considerable simplification of indices. The new values for axes and axial angle, as compared with Dana's, are as follows:

	<i>a</i>	<i>b</i>	<i>c</i>
New	1.9035:1	1.0383	β 96° 44½'
Dana	1.9192:1	0.5245	β 95° 59'

The crystals are ordinarily thick tabular parallel to (100), and usually show the following combination: *c* (001), *a* (100), *m* (110), α (201), δ (112), ϵ ($\bar{1}$ 11), *k* (512). The form *q* (534) was seen on one crystal. In addition a number of new forms were observed, doubtful ones indicated by a question mark: (230?) (540?), (011), (012?), (111), (211), (311), (511), (611), (12.1.1?), ($\bar{6}$ 13?).

EQUILIBRIUM STUDIES ON MIXTURES OF PYROXENES, PYROXENOIDS, MELILITES, AND OLIVINES CONTAINING LIME, MAGNESIA, ALUMINA, AND SILICA

E. F. OSBORN

Data are now complete for the system CaSiO_3 —diopside—anorthite. In this system wollastonite (βCaSiO_3 with diopside in limited solid solution) has a field of stability, but the alleged compound $5\text{CaO} \cdot 2\text{MgO} \cdot 6\text{SiO}_2$ does not appear. The diopside in this system is aluminous. Recently the results on the ternary system CaSiO_3 —akermanite—gehlenite were reported. This system depicts the relations between liquids, pseudowollastonite, and melilite. The various investigations now in progress at the Geophysical Laboratory on phase relations in the quaternary system CaO — MgO — Al_2O_3 — SiO_2 are briefly reviewed.

BOULANGERITE

CHARLES PALACHE AND HARRY BERMAN

Boulangerite, a lead sulfantimonide, has been studied on new material, the first which has proved suitable for detailed crystallographic examination. It is monoclinic, prismatic,

2/*m*, pseudo-orthorhombic. Elements $a:b:c=0.9158:1:0.3456$; $\beta=100^{\circ}39\frac{1}{2}'$. Some 60 crystal forms were observed. Lattice constants (Berry) $a_0=21.14 \text{ \AA}$, $b_0=23.46 \text{ \AA}$, $c_0=8.07 \text{ \AA}$, $\beta=100^{\circ}48'$. New analyses by Gonyer on Washington boulangerite confirmed Shannon's earlier analysis and Berry's cell content of $\text{Pb}_{40}\text{Sb}_{32}\text{S}_{88}$.

DIFFUSE DIFFRACTION AND DISORDER IN MAUCHERITE

M. A. PEACOCK

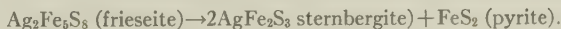
Rotation and Weissenberg photographs of the tetragonal mineral maucherite give series of normal diffractions (*hkl*) with intercalated bands of continuous diffractions (*hk*-). The normal diffractions lead to the unit cell with the symmetry $D^{19}_{4h}=I4/amd$ and a_0 3.422, c_0 21.83; the continuous diffractions indicate horizontal layers with $a'=2a_0$ and no vertical periodicity. The crystal as a whole has the composition $\text{Ni}_{11}\text{As}_8$ or $\text{Ni}_{12-1}\text{As}_8$, and presumably the disorder is related to shortage in Ni. The exact nature of the disorder in maucherite has not been determined. It is thought, therefore, that a review of the evidence, with reproductions of the films, may be of interest and may prompt suggestions leading to a full solution of the problem (*Zeits. Krist.*, **90**, 273, 279, 1935; *Mineral. Mag.*, **25**, 557, 1940).

ON STERNBERGITE AND FRIESEITE

M. A. PEACOCK

Fair crystals of sternbergite (sp. gr. 4.25) from Jáchymov (Joachimsthal), Bohemia, show $c(001)$, $e(011)$, $d(102)$, $t(111)$, $r(263)$, $s(131)$, twin plane (130), on $a:b:c=0.572:1:1.092$ (from *x*-ray measurements). The plane of perfect cleavage and tabular development is (001) and the striations on (001) are parallel to [100]. Rotation and Weissenberg photographs of a good untwinned crystal give the unit cell with a_0 6.62, b_0 11.58, c_0 12.65 \AA , containing $8[\text{AgFe}_2\text{S}_3]$; space group $D^{21}_{2h}=Cmma$, or $C^{15}_{2v}=C2ma$ or $Cm2a$. (*Am. Mineral.*, **21**, 103, 1936; **22**, 847, 1937.)

A typical crystal of frieseite (sp. gr. 4.18–4.31) from the same locality, with $c(001)$, $b(010)$, and a striated zone [010], gives the unit cell with a_0 6.60, b_0 11.59, c_0 12.61 \AA ; space group as in sternbergite. Powder photographs of frieseite show only the pattern of pyrite with weak extra lines corresponding to the strongest lines of sternbergite. In keeping with a warped exterior and a cryptocrystalline interior, frieseite appears to have altered by atomic rearrangement to oriented sternbergite and pyrite, as follows:



MIAROLITIC PEGMATITES IN MONZONITE, BEAVER CREEK STOCK, BEARPAW MOUNTAINS, MONTANA

WILLIAM T. PECORA AND BERNARD FISHER

Thousands of miarolitic pegmatites in monzonite are exposed in a quarry on Beaver Creek, in the Bearpaw Mountains, about 22 miles south of Havre, Montana. The pegmatites are individual bodies having well-defined contacts with host rock, are commonly spheroidal or ellipsoidal in form, and are less than 4 inches in diameter. Each pegmatite is composed of a pegmatitic shell enclosing its miarolitic cavity.

Microperthite tablets and hastingsite prisms are essential minerals of the pegmatitic shell, and biotite, magnetite, and sphene accessory. Epidote, actinolite, chlorite, prehnite, datolite, calcite, analcime, thomsonite, pyrite, galena, and a few unidentified minerals are attached to the inner surface of the shell and extend into the cavity. A crystallographic description and chemical analysis of hastingsite are given.

MINERALOGY OF THE MISSOURI HEMATITE SINKS

FREDERICK H. POUGH

The minerals of the oxidized zones, and so far as possible, the minerals of the unoxidized sulphides, of the filled sink holes of the Central Ore District, centering around Rolla, Missouri, were studied. These deposits have been worked both for the hematite and for the underlying iron sulphides. The hematite formed through the oxidation of the sulphides and varies in texture from soft red "paint ore" to crystallized specularite. Associated with the hematite are numerous other minerals, but in very minor quantities. Among them are azurite, malachite, brochantite, olivenite and native copper. Small quantities of a still unidentified copper vanadate were also found. Calcite, dolomite, siderite, barite and gypsum were common. Chalcantite, pisanite and melanterite formed in the drifts on the timbers. Amethystine and colorless quartz line many of the geodes.

The origin of these deposits presents an interesting problem to which no satisfactory solution has as yet been offered. Among the obviously untenable theories are those based upon the presence of specular hematite, which is shown to be the result of the oxidation of sulphides after deposition, rather than upon initial hypogene solutions. A theory is proposed which involves the deposition of FeS, by anaerobic bacteria, below the floor of a Pennsylvanian swamp, making the original sulphide deposit. The oxide ore is the result of later, and still continuing, supergene alteration.

SETTLING OF HEAVY MINERALS IN A GRANODIORITE DIKE
AT BRADFORD, RHODE ISLAND

ALONZO QUINN

A granodiorite dike at Bradford, Rhode Island, has a thickness of sixty-five feet, an east-west strike, and a dip of 28° south. Heavy mineral separations of samples from different parts of the dike indicate that the proportion of heavy minerals increases systematically toward the base of the dike. This is shown also by thin-section studies of specimens from different parts of the dike and by studies of a dark zone at the base of the dike.

The systematic increase of heavy minerals toward the base seems to be due to crystal settling for several reasons. (1) The minerals which are concentrated toward the base crystallized early in the solidification of the rock. (2) These minerals were considerably heavier than the granodiorite magma. (3) They are distributed through the body of the rock and are not concentrated along permeable zones as they would be if deposited by later hydrothermal solutions. (4) The heavy minerals are especially concentrated in a dark zone along the base and appear to fill depressions in the slightly irregular floor.

The settling appears to have occurred when the magma was moving upward along the dike, as is indicated by the fact that the zones of equal proportions of heavy minerals are almost parallel to the base instead of horizontal. The small size of the settled grains, with zircon crystals as small as .10 millimeters by .03 millimeters, indicates a low viscosity of the magma.

X-RAY CRYSTALLOGRAPHY OF BURKEITE, $2\text{Na}_2\text{SO}_4 \cdot \text{Na}_2\text{CO}_3$

LEWIS S. RAMSDELL

Rotation and Weissenberg photographs of single crystals of synthetic burkeite showed strong reflections indicative of an orthorhombic unit cell with $a_0 = 5.16$, $b_0 = 9.21$ and $c_0 = 7.05$ Å. There are no characteristic absences, although all $h0l$ reflections with $h+l$ odd are either absent or else very weak. This means that the structure must be such as to approximate a diagonal glide plane parallel to 010. If such a glide plane were actually present, the space group would be either $Pmnm$ or Pmn . The axial ratio of this unit cell agrees with that from the morphological data.

This indicated cell, however, contains $4/3(2\text{Na}_2\text{SO}_4 \cdot \text{Na}_2\text{CO}_3)$; hence it must be a

pseudo-cell. Longer exposed rotation photographs about the c and b axes show very faint layer lines trisecting the previously observed strong ones. Weissenberg photographs taken at these new positions are very faint, even after long exposures, but give positive evidence of these layers. Accordingly, the true unit cell has both the c axis and the b axis tripled, with respect to the pseudo-cell. This large unit contains 12 formula weights.

The contents of the pseudo-cell, $4/3(2\text{Na}_2\text{SO}_4 \cdot \text{Na}_2\text{CO}_3)$, may be written as $4\text{Na}_2\text{X}$, where X = either SO_4 or CO_3 . The reason that this pseudo-cell is not the true structural unit must lie in the lack of equivalence of the SO_4 and CO_3 groups. However, these groups are so nearly alike that the evidence for the larger unit is barely apparent. This lack of complete equivalence also probably accounts for the departure from a true glide plane parallel to 010 in the pseudo-cell.

THE MEASUREMENT OF ANGULAR DOMAINS OF REFLECTION IN POLYCRYSTALLINE SAMPLES

ALFRED REIS

Principle of the method: x -ray beam parallelized by reflection on relatively perfect single crystal, powder lines spotted, each diagram made with 2 or more exposures, between 2 subsequent exposures the orientation of sample is given small, definite change ω , ω is varied systematically in a series of experiments.

By shifting the film with each change of sample orientation results are improved. Multiple exposures give more details about different angular domains in sample than double exposures.

Exact theory considers intensities of spots and wavelengths of multiplett x -ray lines.

Details are given on influence of conditions upon number of spots in powder lines and desirable properties of x -ray beam.

Construction of instrument for carrying out measurements is described—type double spectrometer with 2 independent axes.

For measurement of large angular domains (fatigue control) in immovable pieces another instrument is described—type shifting slit.

2 phenomena give their contribution to angular domains of reflection: mosaic structure and fluctuations of lattice constant within a crystallite. The first is independent of the glancing angle, the second increases with $1/\cos \theta$, hence separate evaluation is possible.

By the new method, systematic study of imperfections in crystal structure has become accessible. Interesting applications can be made in metallurgy, especially in the fields of heat treatment (diffusion, transformation, precipitation, age hardening) and fatigue.

INESITE, $\text{Mn}_7\text{Ca}_2\text{Si}_{10}\text{O}_{28}(\text{OH})_2 \cdot 5\text{H}_2\text{O}$

W. E. RICHMOND

The chemical composition of inesite, based on a complete x -ray investigation together with existing analyses is represented by the formula $\text{Mn}_7\text{Ca}_2\text{Si}_{10}\text{O}_{28}(\text{OH})_2 \cdot 5\text{H}_2\text{O}$. Inesite is considered to be a hydrous rhodonite.

A new orientation is adopted.

RANCIÉITE, A VALID MINERAL SPECIES

W. E. RICHMOND AND MICHAEL FLEISCHER

An extensive x -ray, optical, and chemical study of the manganese oxide minerals is now under way at the U. S. Geological Survey. Ranciéite, usually listed as a variety of psilomelane, is a distinct species. A new analysis of material from Cuba leads to the formula $(\text{Ca}, \text{Mn})\text{O} \cdot 4\text{MnO}_2 \cdot 3\text{H}_2\text{O}$. Most of the water is lost below 250° , with the formation of a new phase.

SPHALERITE-DOLOMITE ORIENTATION RELATIONS

FORBES ROBERTSON

The orientation of dolomite and metasomatic sphalerite in two coarsely crystalline, slightly foliated dolomite specimens from the Renfrew Zinc Prospect, Ontario, shows the following features. The crystallographic axes C_2 of dolomite are normal to the foliation. There is remarkable development of (0221) twin doublets which, with the crystal axis orientation, fixes the position of the grains. The orientation pattern supports Fairbairn's assumption of a direction-sense of twinning in dolomite which is the reverse of that known for calcite, and also the hypothesis that the chief stress acted approximately normal to the foliation. Measurement of the dodecahedral cleavage planes of scattered sphalerite grains in the rock reveals a high degree of orientation of their isometric axes, one being parallel to the S-surface, the other two inclined at 45 degrees on either side of the S-surface. The sphalerite is in part elongated parallel to the foliation as a result of movement along cleavage planes. The marked symmetrical relation between the dolomite and later sphalerite suggests an inherited orientation modified by later deformation.

ORDER OF SILICATES IN SYSTEMATIC MINERALOGY

AUSTIN F. ROGERS

The work of structural crystallographers led by Machatschki, Pauling, and W. L. Bragg has furnished a satisfactory classification of silicate minerals based upon the characteristic linkages of silica tetrahedra. While there is general agreement upon the division of the silicates into discrete silica silicates (orthosilicates), chain silicates (metasilicates), sheet silicates (metadisilicates), and network silicates (polysilicates), there is a difference of opinion as to the order of arrangement of these groups. This difference is illustrated in two valuable papers published in the *American Mineralogist* in 1937. In the paper by Swartz the discrete silica silicates are placed first and the network silicates last. In the paper by Berman this order is reversed.

A careful study convinces me that it is better to start with the discrete silica silicates and end with the network silicates. The fact that the network silicates which include the feldspar group are closely related to the silica minerals in structure is of course important, but it does not seem to be a sufficient reason for adopting an order so unsatisfactory in other respects.

In a treatment of silicates, the orthosilicates or discrete silica silicates seem to furnish the logical starting point. Olivine then instead of feldspar takes the position of first place. It is a very important mineral and one much simpler than the feldspars in its chemistry and physical properties.

The order of silicates here advocated is the one preferred by Bayley, W. L. Bragg, Donnay, Escher, Ramdohr, Schneiderhöhn, Strunz, and Wyckoff.

AMERICAN SYNTHETIC EMERALD

AUSTIN F. ROGERS AND FRANCIS J. SPERISEN

The synthetic emerald here described has been made by Carroll F. Chatham, San Francisco chemist, although the method of manufacture cannot be disclosed at present. Cut stones made of the material are small but of very good quality.

The emerald crystals are short prismatic in habit, and in color are comparable to good Colombian emeralds. The chemical analysis shows silica, alumina, beryllia, some chromium oxide, small amounts of alkalis, and small amounts of other constituents.

Optical tests prove that the crystals are emerald. They are slightly pleochroic and show certain optical anomalies.

The synthetic emerald is distinguished from natural emerald by the character of the inclusions.

EXTREME HYDROTHERMAL ALTERATION IN THE BUCK CREEK, NORTH CAROLINA, DUNITE BODY

CLARENCE S. ROSS

A dunite body on Buck Creek, Clay County, North Carolina, is in many ways the most interesting of the many similar bodies distributed from Quebec to Alabama. It is a wedge-shaped mass about $1\frac{1}{2}$ miles long, and $\frac{3}{4}$ of a mile in greatest width. A small part has been described as a troctolite—a rock composed of olivine and calcic plagioclase, but most of the mass appears to have been originally an almost pure olivine dunite. All variations are observable between this and rocks in which olivine has been completely replaced. The secondary minerals are actinolite, chlorite, serpentine, magnesite and magnetite, and less commonly zoisite, indicating an unusually complete degree of replacement of a dunite.

In many of the dunite bodies extreme alteration is related to the introduction of pegmatites and is localized along their contacts; but at Buck Creek, alteration seems to have resulted from the introduction of hydrothermal solutions along closely spaced shear zones. These solutions introduced alumina and lime, and removed magnesia. A rock composed of actinolite, zoisite, and corundum, may have been formed by the same process [though the alteration of a feldspathic rock cannot be excluded].

MUTUAL MELTING RELATIONS OF PYROXENOIDES, MELILITES, AND OLIVINES IN THE QUATERNARY SYSTEM $\text{CaO—FeO—Al}_2\text{O}_3\text{—SiO}_2$

J. F. SCHAIRER

Liquidus data are complete for five planes (joins) through a tetrahedron used to represent the quaternary system $\text{CaO—FeO—Al}_2\text{O}_3\text{—SiO}_2$. The joins studied were $\text{SiO}_2\text{—anorthite—FeO}$, $\text{anorthite—Al}_2\text{O}_3\text{—FeO}$, $\text{CaSiO}_3\text{—anorthite—FeO}$, $\text{gehlenite—anorthite—FeO}$, and $\text{CaSiO}_3\text{—gehlenite—FeO}$. These data give the approximate temperatures and locations of eleven of the quaternary invariant points. It is possible to follow the direction of change in composition of the liquid phase during crystallization in all regions of any geological interest and the incompatibility of certain mineral assemblages at equilibrium is indicated.

AN UNUSUAL SPECIMEN OF GRAPHIC GRANITE

WALDEMAR T. SCHALLER

In a specimen of graphic granite from New Hampshire, the quartz has been completely removed without any change in the microcline. Three similar specimens have been found in California. From specimens from Maryland only a little quartz has been removed.

DIAMOND DIES IN THE NATIONAL DEFENSE PROGRAM

ALEXANDER SHAYNE

The importance of diamonds in the national defense program and the steps taken by the government to develop adequate facilities are discussed. Special attention is given to the wire drawing industry.

The supply, sources of supply, and the industrial requirements of the United States of finished diamond dies in 1940 is presented. The steps taken by the United States Government in cooperation with the British Diamond Die Controller has alleviated the situation. The outlook for the immediate future is discussed.

DIAMOND SET TOOLS

CHESTER B. SLAWSON

The use of shaped cutting tools formed from single crystals is discussed. In forming the contour of the cutting edge a knowledge of the variation in hardness with direction is necessary. In the utilization of the superior hardness of the diamond and the consequent ability "to cut" the other physical characteristics become the primary consideration.

The structural strength of the diamond is due to the absence of fracture and parting, and to its difficult though perfect octahedral and imperfect dodecahedral cleavages. The variation of structural strength with direction is far more pronounced than the variation of hardness with direction. Some evidence seems to indicate that structural strength varies with crystal habit. Industrial practice is correlated with theoretical considerations of maximum structural strength.

Thermal conductivity, thermal expansion, and inversion to graphite are discussed.

MOVEMENT OF MINERALIZING SOLUTIONS IN THE PICHER DISTRICT, OKLAHOMA-KANSAS*

RICHARD E. STOIBER

The direction of flow of the mineralizing solutions was studied at many localities in the mines of the Picher lead-zinc district in Oklahoma and Kansas. Direction of flow was determined from a study of crystals deposited in open space by noting preferred growth on the stoss side of crystals, overgrowths of later crystals on the stoss side of earlier ones and crystal deposition on the stoss side of irregularities in cavity floor or roof. The horizontal components of the flow directions indicate movement of the solutions away from the Miami Shear Trough approximately NE and NW to the NW of the trough and SE and SW to the SE of the trough, with little local variation. These directions are believed to indicate the pattern of the fractures along which solutions traveled in this area. Ore runs appear to have formed when the solutions reached the structures favorable for ore deposition described previously by other investigators.

* Presented through the Geological Society of America.

IDOCRASE MORPHOLOGY

ABBE J. ARTHUR TREMBLAY

From a statistical study of 227 figures in Goldschmidt's *Atlas*, it is possible to list 47 crystal forms in order of decreasing importance (frequency and size). The Donnay method of morphological analysis, applied to these data, yields the space-group $C4/acn$ and the axial ratio $c/a = 0.5372$ (or $P4/nnc$, with $c/a = 0.7597$), in agreement with x-ray results (*Strukturbericht*). The classical Law of Bravais enabled Mallard to determine the lattice mode and axial ratio.

The observed order of importance of the forms is compared with the theoretical order, both in the Law of Bravais and in the generalized law (Donnay and Harker). The agreement is better in the latter, although some anomalies persist.

NOTE ON THE TERMINOLOGY OF CRYSTAL DRAWINGS

GEORGE TUNELL

In order to obtain crystal drawings of a more solid appearance than the ordinary plan, front elevation, and side elevation, two methods have been widely used. In one the drawings are constructed by laying off intercepts of crystal faces on an axial-cross; in the other the drawing is constructed from a gnomonic projection. The greater part of the drawings made by the axial-cross method have been clinographic projections, that is, the projection lines from the crystal to the drawing plane are not perpendicular to the drawing plane. The method of preparing a solid-appearing crystal figure from the gnomonic projection, which was discovered by V. Goldschmidt, leads to an orthographic projection of the crystal on a plane not parallel to any of the principal planes of the crystal. Such a drawing has frequently been called a parallel-perspective drawing by crystallographers. It has been pointed out by A. F. Rogers, however, that this term is used in architectural and engineering drawing in an entirely different sense. A term has long existed for orthographic projections on planes

not parallel to any of the principal planes of the object, namely, axonometric projection. Since this term is generally used in engineering drawing and descriptive geometry, it should be used for crystal drawings made by the method of V. Goldschmidt, as well as for some drawings made by the axial-cross method that are orthographic projections. The term axonometric is derived from the Greek *αξων* axis and *μετρον* measure. The axonometric projection is one in which measurements can be made along directions parallel to the three axes of the object, scales of foreshortening determined by the angles made by the plane of the projection with these three axes being applied in the axial directions.

X-RAY STUDY OF CHRYSOTILE ASBESTOS

B. E. WARREN

A previously proposed structure for chrysotile asbestos involving Si_4O_{11} chains is considered now to be improbable. It appears that a ribbon structure involving long but narrow Si_4O_{10} sheets is more probable than one involving the double amphibole chains. The composition $\text{Si}_2\text{O}_5 \text{Mg}_3(\text{OH})_4$ has a silicon-oxygen ratio indicating a sheet structure, and it was only the fibrous nature of the material which suggested a chain structure.

Chrysotile from Thetford Mines has been re-examined using crystal monochromated $\text{CuK}\alpha$ and $\text{MoK}\alpha$ radiation. All reflections can be indexed in terms of a monoclinic cell $a = 14.66 \text{ \AA}$, $b = 9.24 \text{ \AA}$, $c = 5.33 \text{ \AA}$, $\beta = 93^\circ 16'$, with c the fiber axis. Except for two or three weak reflections half this value of a will suffice. The most obvious layer structure is one built up by the sequence 3O , 2Si , 2O OH , 3Mg , 3OH . The two dimensions $b = 9.24$ and $c = 5.33$ are identity periods in such a layer. Satisfactory intensity agreement is obtained for eight observed orders of $h00$ only if the layers all face the same way.

All of the definite reflections are of the type $h0l$ or $0kl$. All $h0l$ reflections are of the sharp crystalline type, most of the $0kl$ reflections are smeared out along the layer lines resembling two-dimensional lattice reflections (kl). The diffuse reflections are due to a randomness in the stacking together of successive layers. Although the main features of the structure seem to be fairly definite, a complete treatment of the intensities of the diffuse and the sharp reflections has not been finished.

FURTHER STUDIES IN THE LEPIDOLITE SYSTEM

A. N. WINCHELL

Detailed study of all the best analyses of the lepidolite system, including five new ones, together with x-ray and optic studies of the samples analyzed, leads to the conclusion that the system has three end-members, namely polyolithionite, $\text{K}_2\text{Li}_4\text{Al}_2\text{Si}_8\text{O}_{20}\text{F}_4$, protolithionite, $\text{K}_2\text{LiFe}_4\text{Al}_3\text{Si}_6\text{O}_{20}\text{F}_4$, and $\text{K}_2\text{Li}_3\text{Al}_5\text{Si}_6\text{O}_{20}\text{F}_4$, for which the name paucilithionite is suggested. But on this basis alone practically all the analyses show a deficiency of lithia which is too constant and too large to be ignored. No change in the end-member molecules has been discovered which will reduce this deficiency. All the evidence leads to the tentative conclusion that it is due to muscovite, not in crystal solution in the lithia mica, but submicroscopically interleaved with it. Diagrams are presented showing the relations between variations in composition and variations in the optical properties.

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 Department of Natural Resources, Division of Mines, State Capitol, Atlanta, Georgia.
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 Museum, Ottawa, Canada.
 Geological Survey of Great Britain, Exhibition Road, London SW. 7, England.
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- Geological Survey of Kiangsi, Taiho, Kiangsi, China.
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Geological Survey of South Africa, Department of Mines, Pretoria, South Africa.
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Geologisk Museums Bibliotek, Trondhjemsveien 23, Oslo, Norway.
Geophysical Laboratory, 2801 Upton Street, Washington, D. C.
Georgia School of Technology Library, Atlanta, Georgia.
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PROCEEDINGS OF SOCIETIES

NEW YORK MINERALOGICAL CLUB, INC.

The American Museum of Natural History, New York City

Meeting of Oct. 15, 1941

The deaths of Dr. Olaf Anderson, Mr. James A. Morton, and Mr. Horace A. Woodward were announced and eulogies read.

The meeting was devoted to reports by the members on summer collecting. Mr. Leonard Morgan exhibited very fine smoky quartz crystals from Lovejoy's gravel pit at North Conway, N. H.

Mr. Northup showed samarskite, euxenite, uraninite, torbernite, garnet, and emerald crystals from Mitchell County, North Carolina, and large crystallized pyrite concretions from a clay bed at Sayreville, N. J.

Mr. O. Ivan Lee found excellent dufenite at Midvale, Rockbridge Co., Va. He also reported that the Morefield mine at Amelia, Va., is soon to be worked for tantalite again. Mr. Peter Zodac showed a large black tourmaline crystal from Bachelor's Ridge, Saratoga County, N. Y.

Meeting of Nov. 5, 1941

Mr. E. A. Maynard spoke on the subject: "Rambling through the West." His talk was illustrated with a large number of colored slides and specimens of shattuckite, wulfenite, diopside, azurite, vanadinite, and malachite.

Meeting of Nov. 19, 1941

Mr. Grahl reported on the fall excursion to the Strickland and Schoonmaker quarries on Collins Hill near Portland, Conn. The usual minerals were found in abundance as well as a number of fine specimens of bertrandite.

Mr. Trainer then introduced the speaker of the evening, Dr. J. F. Schairer of the Geophysical Laboratory of the Carnegie Institution of Washington, whose talk was entitled "The relations between olivines, pyroxenes and melilites in igneous rocks."

The studies at the Geophysical laboratory on the melting relations of silicates were described. Dr. Schairer discussed in detail by means of phase equilibrium diagrams the chemical and melting relationships of the molecules of the olivines, pyroxenes, and melilites. All of these show extensive solid solutions. Many binary and ternary diagrams were explained and by means of a tetrahedral model, the complex relations between the lime-iron olivines, the $\text{CaSiO}_3\text{-FeSiO}_3$ pyroxenes and pyroxenoids and the gehlenite-iron ackermanite melilites in the quaternary system $\text{CaO-FeO-Al}_2\text{O}_3\text{-SiO}_2$ were shown.

Meeting of Dec. 17, 1941

Mr. Leo Neal Yedlin spoke on "Collecting Minerals in Maine." He discussed the five stages in the formation and subsequent alteration of pegmatites in Maine and reported on specimens found at various Maine localities; among these were: large twinned hercynite crystals, blue topaz, small samarskite and monazite crystals from Topsham; quartz casts after heulandite, (?) white and blue tabular apatite, and bertrandite from Greenwood; pollucite, triphylite and purpurite-heterosite from Newry; large lepidolite crystals from Mt. Apatite; large radiating masses of rubellite, caesium beryl, eosphorite, childrenite, and uraninite from Black Mt. at Rumford; splendid brown garnet crystals from Minot; as well as biotite crystals from Standpipe hill. These specimens were exhibited along with other type specimens of Maine minerals which the speaker had borrowed from older collections.

M. ALLEN NORTHUP, *Secretary*